APR 8 1945

MARCH 1945
NO. 411 VOL. 49
SEVEN SHILLINGS
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The Journal of THE ROYAL AERONAUTICAL SOCIETY

THEY WHO LOOK AHEAD

The time will come when thou shalt lift thine eyes
To watch a long drawn battle in the skies,
While aged peasants, too amazed for words,
Stare at the Flying Fleets of wond'rous birds.
England, so long Mistress of the Sea,
Where wind and waves confess her sovereignty,
Her ancient triumphs yet on high shall bear,
And reign, the Sovereign of the conquered air.

Gray's "Luna Habitalis" 1737

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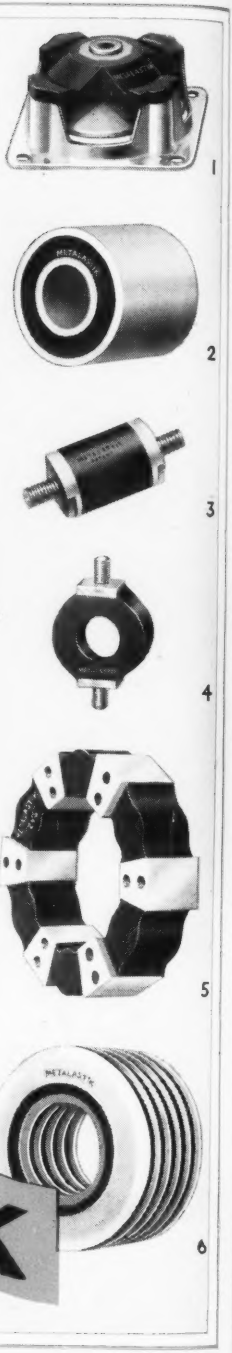

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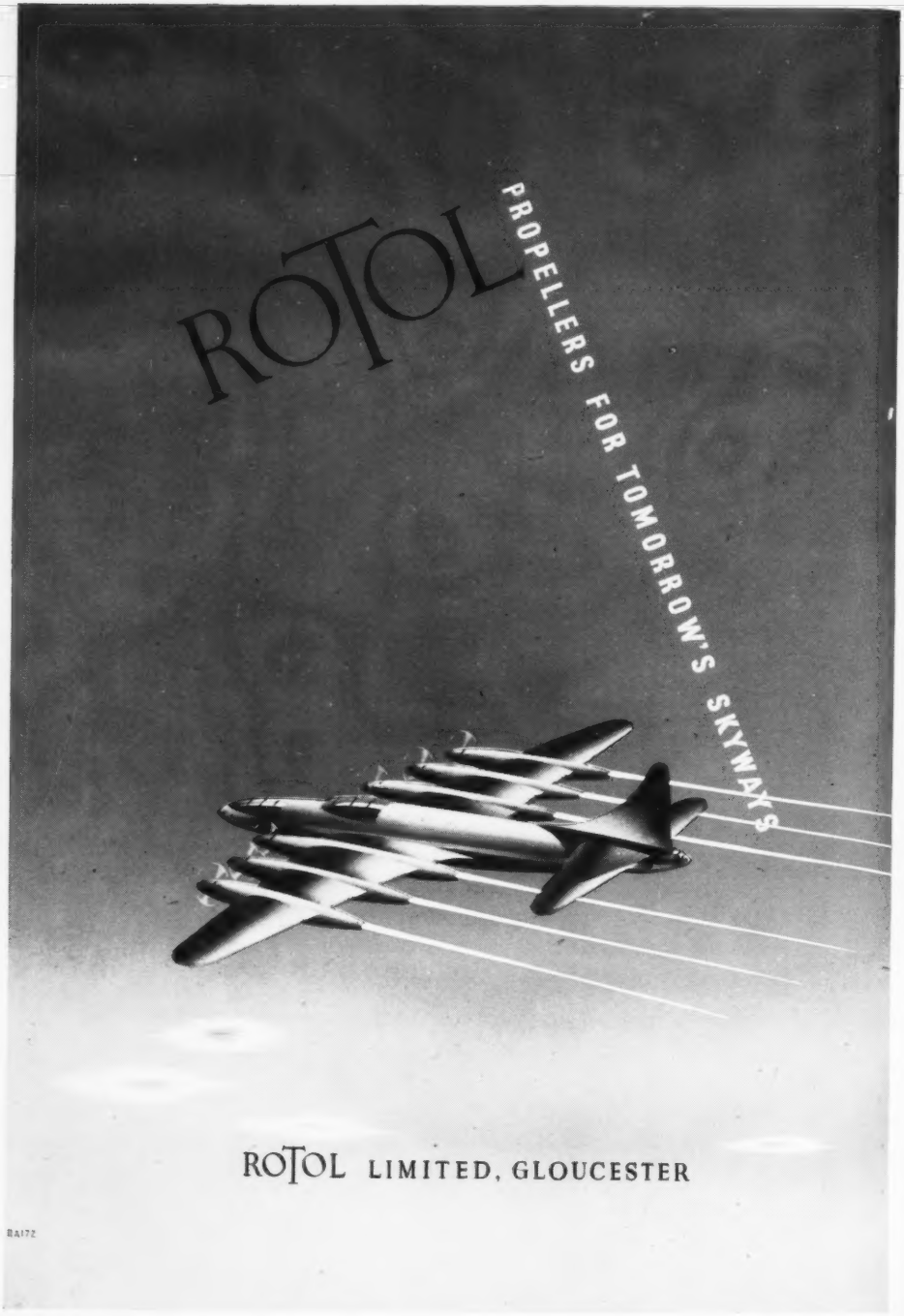
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The Society offers a number of valuable prizes, most of them annually. Full particulars of the conditions attaching to the awards of these prizes may be obtained on application

Society's Gold Medal

This is the highest honour which the Society can confer for work of an outstanding or fundamental nature in aeronautics.

British Gold Medal for Aeronautics

The British Gold Medal for Aeronautics is awarded for an achievement leading to advancement in aeronautical science.

Simms Gold Medal

The Simms Gold Medal is awarded annually for the best paper read in any year before the Society on any science allied to aeronautics, e.g., meteorology, wireless telegraphy, instruments.

The George Taylor (of Australia) Gold Medal

The Taylor Gold Medal is awarded annually, at the discretion of the Council, for the most valuable paper submitted or read during the previous session.

Wakefield Gold Medal

The Wakefield Gold Medal is awarded annually to the designer of any invention or apparatus tending towards safety in flying, and is open to members or non-members.

Society's Silver Medal

The Society's Silver Medal is awarded, at the discretion of the Council, for some advance in aeronautical design.

British Silver Medal for Aeronautics

The British Silver Medal for Aeronautics is awarded for an achievement leading to advancement in aeronautical science.

Society's Bronze Medal

The Society's Bronze Medal is awarded, at the discretion of the Council, under the same conditions as those for the Silver Medal, but for some less important advance in aeronautical design.

Wilbur Wright Memorial Premium

The Wilbur Wright Memorial Lecture is held annually, a premium of fifty pounds being awarded to the lecturer invited by the Council to deliver the lecture. The lecture is usually given alternately by an American and an Englishman, and is the most important aeronautical lecture of the year. It is delivered whenever possible, on the last Thursday in May of each year.

British Empire Lecture

The Council of the Royal Aeronautical Society have completed the arrangements for the founding of a British Empire Lecture.

The lecture, on any aeronautical subject approved by the Council, will be delivered annually in September in London, by a lecturer, chosen in alternate years from the British Dominions and Colonies and Great Britain.

The Council, by founding this British

Empire Lecture, are anxious to encourage new ideas and new points of view from all parts of the British Empire, and to make the Lecture second only in importance to the Wilbur Wright Memorial Lecture.

The British Empire Lecture will have a premium of £50 attached to it, and in the case of lecturers coming from the Dominions and Colonies an allowance up to £100 will be paid towards the Lecturer's expenses.

It is proposed to hold the first lecture in September, 1945, and suggestions for lecturers should be received by May 31st, 1945, at the latest.

R.38 Memorial Prize

The R.38 Memorial Prize is offered annually for the best paper received by the Society on some subject of a technical nature in the science of aeronautics, preference being given to papers which relate to airships. The prize is twenty-five guineas.

The Herbert Akroyd Stuart Lectures

Under the will of the late Mr. Herbert Akroyd Stuart a sum of £700 is held in trust by the Society for the offer of a prize every two years, for the best paper or lecture read or given before the Society dealing with the Origin and Development of Heavy-oil Aero Engines. The prize is open to members and non-members.

Edward Busk Memorial Prize

The Edward Busk Memorial Prize is offered annually for the best paper received by the Society on some subject of a technical nature in connection with aeroplanes (including seaplanes). Its value is twenty guineas.

Pilcher Memorial Prize

The Pilcher Memorial Prize is offered annually, at the discretion of the Council, for the best paper by a Student on heavier-than-air craft or any analogous subject. Its value is five guineas.

Usborne Prize

The Usborne Prize is offered annually, at the discretion of the Council, for the best paper by a Student on some subject in connection with Aero Engines. Its value is five guineas.

Major Baden-Powell Memorial Prize

The Major Baden-Powell Memorial Prize is awarded in May and December of each year to the student who is considered the best student by the examiners in the Society's Association Fellowship examinations. Its value is three guineas.

Elliott Memorial Prize

The Elliott Memorial Prize is awarded twice yearly to the apprentice at Halton who has the highest percentage of marks in the passing-out examination. Its value is 2½ guineas for each award.

R. P. Alston Memorial Prize

The R. P. Alston Memorial Prize is awarded to any Graduate or Student of the Society for work done leading to improvement in the safety of aircraft, and particularly for improvement in stability and control. Its value is approximately £5.

Branch Prize

The Council offer an annual prize of twenty guineas for the best paper read before the Branches during the previous lecture Session. The prize is open to any member of the Society or of any Branch.

Journal Premium Awards

The Council has set aside an annual sum of £250 to be given as premium awards to authors of papers published in the Journal.

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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY

With which is incorporated The Institution of Aeronautical Engineers

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The Journal of The Royal Aeronautical Society was founded in 1897 in succession to the Annual Reports. For the opinions expressed in Papers that are signed or initialled the authors alone are responsible. None of the papers or paragraphs must be taken as expressing the opinion of the Council of The Royal Aeronautical Society unless such is definitely stated to be the case. **The Journal is published monthly at the Offices of the Society, 4, Hamilton Place, Piccadilly, London, W.1.** Subscriptions per annum, £4 10 0 post free; Single Numbers 7/6 or 7/9 post free. All communications for publication in the Journal, or on general matters affecting the Society should be addressed to—The Secretary, J. Laurence Pritchard, 4, Hamilton Place, W.1. The Society's Bankers are Messrs. Coutts and Co. All communications respecting Advertisement matters should be addressed to—The Advertisement Manager, Journal of The Royal Aeronautical Society, 4, Hamilton Place, W.1.

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MARCH NOTICES 1945

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members will contribute papers on their own special subjects.

Assistant Librarian

A vacancy occurs at the Society for an assistant librarian. A knowledge of languages will be an asset. Applications for the post should be made to the Secretary.

Lectures 1945

The following programme of lectures has been arranged to be held, with the exception of the discussions on Civil Aviation, at 6.30 p.m. in the Lecture Hall of the Institution of Mechanical Engineers, Storey's Gate, St. James', S.W.1 (by permission of the Council of the Institution). Members do not need admission tickets, but visitors must obtain a ticket through a member.

Thursday, 22nd March—Hydraulics for Aircraft, by Mr. R. H. Bound, F.R.Ae.S.

Thursday, 5th April—Modern Experimental Work on Aeroplane Structures, by Dr. A. G. Pugsley, F.R.Ae.S.

Monday, 16th April—Debate on Civil Aviation.

Thursday, 31st May—33rd Wilbur Wright Memorial Lecture, by Mr. T. P. Wright, Hon.F.R.Ae.S.

Branch Lectures

MEDWAY BRANCH

Lectures are held at 6 p.m.

Monday, 9th April—Work in an Experimental Seaplane Tank, by Mr. L. Smith.

BELFAST BRANCH

Lectures are held in the Central Hall, College of Technology, at 6.30 p.m.

Monday, 26th March—Inspection, by Mr. W. H. Bell, A.F.R.Ae.S.

Monday, 16th April—Test Flying, by Mr. J. Lankester Parker, F.R.Ae.S.

BIRMINGHAM BRANCH

Lectures held in the University, Edmund Street, at 6.45 p.m.

Wednesday, 11th April—Short Papers by Members, followed by an "Aeronautical Brains Trust."

BRISTOL BRANCH

Lectures are held in the Conference Room, Bristol Aeroplane Company, Filton House, Bristol, at 6.30 p.m., by kind permission of the Directors.

Tuesday, 20th March—Film Night and Annual General Meeting.

DERBY BRANCH

Lectures are held in the Rolls-Royce Welfare Hall, Nightingale Road, at 6.30 p.m.

Monday, 9th April—Gas Turbines for Beginners, by Dr. S. G. Hooker.

Monday, 7th May—Shock Waves at Sonic Speeds, by Dr. W. E. Hilton, B.Sc., A.R.S.C.

GLASGOW BRANCH

Saturday, 21st April—Visit to Prestwick Aerodrome, followed by a lecture by Mr. R. McIntyre, A.F.R.Ae.S.

LUTON BRANCH

Wednesday, 4th April—Propeller Developments, by Mr. D. A. Cleaver.

Wednesday, 2nd May—The Development of Civil Aircraft, by Mr. N. A. White.

Wednesday, 23rd May—Hydraulics for Aircraft, by Mr. R. H. Bound, F.R.Ae.S.

Wednesday, 6th June—Design and Operation of Deck Landing Aircraft, by Mr. G. E. Petty, F.R.Ae.S.

PORTSMOUTH BRANCH

Lectures are held in the Oddfellows Hall, Kingston Road, Portsmouth.

Thursday, 22nd March—First Principles of Grinding, Film demonstration.

Re-Opening of Branches

The Coventry and Southampton Branches of the Society are re-opening. Anyone who is interested and is living in these areas should contact the local secretaries.

Graduates' and Students' Section

Wednesday, 4th April—Annual General Meeting of Section at 7.30 p.m. Representatives of groups outside London should make a special effort to attend this meeting.

Election of Members

Associate Fellows

David Charles Appleyard (from Student), Joseph Dover Atkinson, Kenneth MacDonald Beaumont, Harold William Bennett, Clarence Henry Cumberland, Rowland Burnstan, Francis Joseph Delves (from Associate), Stanislaw Dudzinski, Sidney Vernon Fagg, Wladyslaw Fiszdon, Tormod Olaf Fjaerem (from Associate), Howard Poulsom Forder, Walter Eric French, Donald Gardiner, Maurice Lawson Hall (from Graduate), Donald Henderson, Wesley Hill, Harry Geoffrey Hopkins, Leonard Maxwell Hoskins, Albert William Hotson, Ernest Leslie Howard-Williams, Francis Albert Kappey, Francis Lentel, John Leslie Longden (from Student), William Austyn Mair, Eric Mensforth, Walter Frederick Mountney, Ernest Frederick Needham (from Graduate), John Poole (from Graduate), Arthur William Pope (from Student), Richard Alan Slade Reid, Anthony James Cotter Smith (from Graduate), Ernest Oscar Tips, Victor Henry Wilton.

Associates

Albert Walter Alldrit, Thomas Edward Seymour Bell (from Companion), Bernard Frederick Billing, George Halley Brown, Gordon McLaurin Brown, Laurance Valentine Brown (from Student), Charles Reginald Burgess, Francis William Burnard, John Hyde Mayo Canning (from Student), Gerald Andrew Clayton, Alan Bremner Coates (from Student), John Coley, James Cecil Coombes, George Frederick Ernest Cumberland, Norman Davis, Herbert Deakin, Harold Dewey, Francis Dobson, Alfred John Douch (from Student), Thomas Ross Dowson, Peter Dunning, Archibald James Edmunds, Geoffrey Basil Fage, William Rutherford Farrington, Charles Henry Fowler, Harris Freedman, Veryl Clifford Freeman, John Alexander Gale, John Herrmann Gausden, Peter Graham, Frederick Cornelius Hanbury, George Raymond Heard, S. Harrop, Frederick Bernard Hollins, Gerald Lindsay Hunting, Frederick George Jeans, Harry Lloyd Jenkins, Cyril Herbert Johnson, Kenneth John Robert Lane, William Colebank Leech, Gerald Oke Manning (from Student), John Mulligan, Richard Muspratt, John Nash, Alfred Stanley Neal, Leonard Alfred William Newman, Albert Oldfield, Victor Charles Otter, Albert Leslie Ottway, A. Papathanassiou, William Richard Parkhouse, Peter Athelwold Pennant-Rea, John Ramsom Pickard, Charles Gibbs Potts, Jack Purdey, Albert Rickards, Albert Harold Richards, Rowland Rostron, Frederick Gordon Ryder, Charles Frederick Sarsby, Frank Stanley Saunders, Frederick James Scutts, John Howard Marcus Smith, Frederick John Slocombe, Geoffrey Thomas, Charles Gran-

ville Thorpe, Cyril Frederick Vercoe, Leslie Edward Vine, Charles Henry Wattiez, William Wilkinson, Albert Edward White, John Benson Wood, Frederick John Woodland, Alfred Woolgar, Som Nath Zadoo.

Graduates

Robert Hastings Adams (from Student), John Elliston Allen (from Student), Trevor Ronald Ashcroft, Frank Ashton (from Student), John Evelyn Clausen (from Student), Arthur Cooke, Frederick Russell Daniels (from Student), Francis Victor Davies (from Student), Ernest John Hancock, John Henry, Julian Leslie, Kenneth Granger Lunn, William Stanley Donald Marshall (from Student), Ian Black Matheson, Peter Mitchell (from Student), John Mowbray Morton (from Student), John Garry Owen, Clifford Henry John Partridge, Geoffrey Ratcliffe (from Student), Stanley Raymond, John Shields (from Student), John Richard Thirkettle (from Student), Trevor Harry Thornton (from Student), Charles Henry Webb, John Frederick Butler Welch.

Students

Donald Anderson, Frank Henry Bellis, Kenneth Gordon Blackmore, David Richard Blundell, Edgar Alfred Bridle, Geoffrey Albert Diamond Brittain, Ilka Erik James Bowles, Peter Lawrence Britton, Hazel Florence Brookes, Anthony Robert Burge, Jasper Stephen Butcher, Brian Robert Carter, Richard Henry Collins, Donald Meldrum Congreve, Gordon Alasdair Crompton, Gordon Davies, John Anthony Dunsby, Albert William East, John Harold Edwards, Brian William Firth, Philip John Fletcher, Norman William Furneaux, George Frederick Gilmore, William Good, Alan Grant Hartnall, Robert Ian Hazlehurst, Bernard Oliver Heath, Michael James Henwood, Cyril Robert Homes, William Racine Hudson, James Ivor James, Peter Robert Keeble, Sidney Levy, Gordon Walter Little, James John Lovelock, Lawrence Halford Warren Ellis Luckraft, William McIlroy, John Mackereth, Kenneth Alfred Major, John Walton Martyr, Carlos Lorenzo Merino, Charles Granville Pawson, Brian Stanley Pittaway, Raymond James Potter, Derrick Cecil Carson Peacock, Harold Yeoman Ratcliffe, Colin Walter Rhodes, Frank Edwin Roe, Eric William Evan Rogers, Peter Desmond Savitsky, Graham James Silvester, Kenneth Cecil Slowman, Guy Thornton Smith, Gustave Souchotinsky, Peter Henry Southwell, Stanley Arthur Stephenson, Walter Robert Stirling, Sidney Michael Taylor, Geoffrey Swan Cabat Vautier, Frank Malcolm Warner, David John Weeks, Ernest Bertram Weston, Ernest Wilks, Peter James Windibank, Cyril Winstanley, John Leonard Wood, Ronald Bruce Wyke, Edward Wilson Whitley.

Companions

Terence Devine, Charles Harvard Gibbs-Smith.

Associate Fellowship Examination Results

The following candidates were successful in the Associate Fellowship Examinations held in London in December, 1944:—

Anderton, R. A. P., Applied Mathematics, Theory of Machines, Design (Aero Engines), 1st Place; Ayers, K. B., Design (Aircraft); Basu, B. N., Pure Mathematics, Theory of I.C. Engines; Benton, J. L., Pure Mathematics, Aerodynamics, Design (Aircraft); Blanchard, W. T., Pure Mathematics, Strength of Materials, Design (Aircraft), 1st Place; Blundell, D. R., Pure Mathematics; Botting, B. A. H., Applied Mathematics, Theory of Machines, Design (Engines); Brazier, R. C. G., Pure Mathematics, 1st Place; Brooks, H. J., Pure Mathematics, Strength of Materials; Carson, M. J. G., Air Transport; Conea, M. M., Pure Mathematics; Edwards, B., Theory of Machines, 1st Place; Gallia, G. W., Wireless Telegraphy; Gasson, Miss U. A., Applied Mathematics; Gilbert, J. K., Pure Mathematics; Hatton, C. D., Applied Mathematics; Jones, C. Neville, Applied Mathematics, 1st Place, Theory of

Machines, Design (Aero Engines) (Baden-Powell Memorial Prize); Kennedy, G. A., Applied Mathematics; Korda, H., Pure Mathematics, Navigation, Theory of I.C. Engines; Levy, G. G., Applied Mathematics, Theory of I.C. Engines, Design (Aero Engines); Lubell, D. S., Applied Mathematics; MacDonald, A. J., Applied Mathematics, Design (Aero Engines); Milligan, F. J., Strength of Materials; Naylor, J. S., Pure Mathematics; Pickett, V. C., Applied Mathematics; Rider, G. H., Pure Mathematics, Theory of I.C. Engines, 1st Place, Aircraft Materials; Risdon, J. H., Applied Mathematics; Saravanos, B., Pure Mathematics; Saunders, P., Pure Mathematics, Aerodynamics; Sheikh, G. M., Theory of Machines; Smith, S. J., Aerodynamics; Sowter, R. S., Navigation; Starr, E. V., Applied Mathematics; Stevenson, P. E. A., Applied Mathematics; Thompson, W., Strength of Materials; Wallington, C. E., Applied Mathematics, Meteorology; Walsh, R. H., Applied Mathematics.

Acknowledgments

The Council acknowledge with thanks the gift of Journals from Lieut. R. C. Abel, R.N.V.R. (Associate Fellow), and Mr. H. E. Adams (Associate).

New Year's Honours List

Wing-Commander D. McDonald (Associate) was awarded the M.B.E. in the New Year's Honours List (see February Journal).

Additions to the Library

Pamphlets in italics with location reference following in brackets.

Books marked * or ** may not be taken out on loan.

*B.g.143.—The Aircraft Recognition Manual. C. H. Gibbs-Smith. British Aviation Publications (per George Newnes Ltd.), 1944. 7/6.

*B.g.144.—Basic Aircraft Recognition. C. H. Gibbs-Smith. Country Life Ltd., 1943. 5/-.

BB.a.14.—The Flying Machine from an Engineering Standpoint. F. W. Lanchester. Constable & Co., 1916. (2nd copy.)

BB.c.93.—The Repair and Maintenance of Jablo Wood Propeller Blades. F. Hills & Sons Ltd., Manchester, 1944.

BB.c.94.—De Havilland Controllable Pitch Airscrew Service Manual (Revised Ed.). De Havilland Aircraft Co. (ca. 1940).

BB.c.95.—De Havilland Controllable Pitch Airscrew, Constant Speed: Spring and Pressure Operated Types (Service Manual). De Havilland Aircraft Co. (ca. 1940).

BB.c.96.—Hydromatic Quick-Feathering Propellers (Models 25E50-31 and above) Service Manual. Hamilton-Standard Propellers, 1938.

BB.c.97 and 98.—*Making the De Havilland Variable-Pitch Airscrews. Reprint from "Machinery," May 18, 25, June 1, 8, 15, 1939. (2 copies.)* (Y.7.a.18 and 19.)

BB.f.52.—Smith's Aircraft Instruments. (Loose-leaf Catalogue.) 1940.

**BB.f.53.—The Distant-Reading Gyro-Magnetic Compass. Ministry of Aircraft Production. (Per Automatic Telephone & Electric Co. Ltd.) 1945.

D.a.A.31.—*Air Power: Estimate of American Aviation and Recommendation for a Policy of American Air Power. Aeronautical Chamber of Commerce Inc., U.S.A.*, 1944. (Y.37/5.)

D.c.100.—Airport Engineering. H. O. Sharp, G. Reed Shaw and John A. Dunlop. John Wiley & Sons, 1944. $5.

D.d.24.—*Scheme for a Degree Course in Chemical Engineering. Institution of Chemical Engineers*, 1944. (PE.2.b.17.)

E.b.102.—Aircraft Vibration and Flutter. C. R. Freberg and E. N. Kemler. John Wiley & Sons, 1944. $3.

E.d.24.—Manual of Aircraft Layout. R. Faltus and C. Steinmetz. John Wiley & Sons, 1944.

G.e.D.24.—Plastics. V. E. Yarsley and E. G. Couzens. Penguin Books Ltd., 1941. 9d.

*G.e.E.63.—Tables and Data (Steel). Arthur Lee & Sons, Sheffield (undated).

J.g.207.—*Smithsonian Institution Reprint. No.* 3750. The Ocean Current called "The Child." Eliot G. Mears, 1944. (Y.30.ii.61.)

L.b.42.—"Flight" Handbook (4th Ed.). Edited by G. Geoffrey Smith. Flight Publishing Co., 1945. 7/6.

L.j.93.—*Camouflage and its Application to Peace-time Purposes. Wing-Com. T. R. Cave-Browne-Cave. (Lecture before Royal Society of Arts, Feb.* 14, 1945.) (Y.16/23.)

N.A.83.—Low Temperature Physics. L. C. Jackson. Methuen & Co., 1934. 2/6.

*Q.b.75.—Catalogue of Lewis's Medical, Scientific & Technical Lending Library. (Revised to end of 1943.) 1945. 25/- (12/6 to Subscribers).

*X.a.55.—Engineering Handbook. British Timken Ltd. (undated).

*X.a.B.24.—Aviation Dictionary and Reference Guide (Aero-Thesaurus). Harold E. Baughman. Aero Publishers, Los Angeles. $6.50.

*X.e.54.—Aeronautical Engineering Catalog. Institute of Aeronautical Sciences, U.S.A., 1944.

J. LAURENCE PRITCHARD,
Secretary.

On the solution of the numerical

SIMULTANEOUS EQUATIONS

arising in the analysis

OF REDUNDANT STRUCTURES

by

F. J. TURTON, B.Sc., A.R.C.S.

F. J. Turton took his B.Sc. with honours at London University in 1914, and served in the Royal Navy, 1915-1919. Following his demobilisation he became a lecturer in mathematics at the City and Guilds College. He has written numerous papers on structural problems which have been published in the Philosophical Magazine and the Journal of the Society.

1. The application of strain energy or slope-deflection methods in the analysis of redundant structures leads to a number of simultaneous linear equations with numerical coefficients; the equations may be obtained in such order that each successive equation contains one new unknown, until all the unknowns are so included. This is the only condition essential for the method to be described in the present paper, but the labour is much reduced in slope-deflection and strain energy applications by the fact that most (or all) of the equations contain very few of the unknowns. The method to be given reduces the solving of these equations to a column of successive evaluations, followed by the solution, by algebraic methods, of a small number of simultaneous equations; and a final column of evaluations. In the remaining paragraphs a number of problems are examined to show how the equations may be obtained in suitable sequence for the method to apply. Following an application to the determination of secondary stresses, the operations involved in the moment-distribution method and in this method are compared. A numerical example is worked out in the simple case of §2, and it is shown how any order of mathematical accuracy in the roots may be ensured, provided that sufficient figures have been retained to permit that accuracy.

Paper received March, 1945.

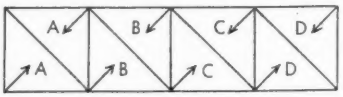


Fig. 1

2. Fig. 1 represents a structure which is statically determinate except for the redundant diagonal braces, which, for the application of Castigliano's Theorem of minimum strain energy, are replaced by pairs of forces A, B, C and D as in the figure. Then if U_T is the total strain energy of the structure, including the redundant bars (which are assumed to have no initial lack of fit), we have $\partial U_T/\partial A = 0$, $\partial U_T/\partial B = 0$, etc. Now the force diagram for the two forces A, A alone involves only that rectangular panel, along the diagonal of which the forces A, A act; U_T will contain six terms containing A (for four sides and two diagonals of the rectangle); one of these will contain B also (for the right-hand bar). Thus $\partial U_T/\partial A = 0$ gives an equation in A and B only. Similarly the six terms containing B

will include one containing A (for the left-hand bar of the rectangle along the diagonal of which B, B act) and one containing C (for the right-hand bar). Hence $\partial U_T/\partial B=0$ gives an equation in A, B and C only. Similarly $\partial U_T/\partial C=0$ gives an equation in B, C and D only and $\partial U_T/\partial D=0$ one in C and D only.

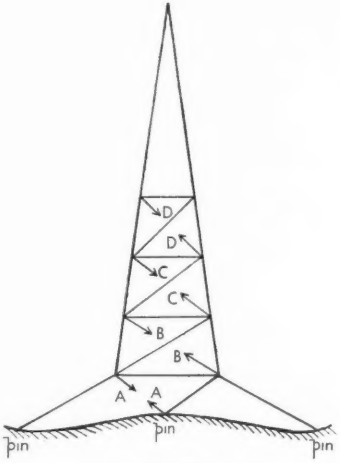


Fig. 2

In Fig. 2 there is one redundancy in addition to the diagonal bracing; this we take as A, *avoiding the panel across which the diagonal of which B acts*; we get equations in A and B, A, B and C, B, C and D, and in C and D, just as in the frame of Fig. 1.

The equations will be of the following form, the α's being numbers

$$\alpha_1 A+\alpha_2 B-\alpha_3=0 \qquad (1)$$

$$\alpha_4 A+\alpha_5 B+\alpha_6 C-\alpha_7=0 \qquad (2)$$

$$\alpha_8 B+\alpha_9 C+\alpha_{10} D-\alpha_{11}=0 \qquad (3)$$

$$\alpha_{12} C+\alpha_{13} D-\alpha_{14}=0 \qquad (4)$$

Use (1), (2) and (3) to put B, C and D in succession into terms of A, say

$$B=\alpha_{15}+\alpha_{16} A \qquad (1.1)$$

$$C=\alpha_{17}+\alpha_{18} A \qquad (2.1)$$

$$D=\alpha_{19}+\alpha_{20} A \qquad (3.1)$$

Substituting in (4) from (2.1) and (3.1) gives, say

$$\alpha_{21} A-\alpha_{22}=0 \qquad (4.1)$$

from which A can be found.

If no rounding-off has been done at any stage, the exact value of A now substituted in (1) finds B, thence (2) finds B, thence (3) finds D. Finally, the values so found substituted in the left-hand side of (4) would give exactly zero and confirm all the values.

But in practice rounding-off is almost inevitable. Suppose therefore that A is rounded to A' and on substitution, (1), (2) and (3) in turn give B', C' and D'. Further, let $A'=A+a$, $B'=B+b$, $C'=C+c$, $D'=D+d$, A, B, C and D being the exact roots and a, b, c and d the errors. Then when A' is put in (1) to find B' we have

$$\alpha_1 A'+\alpha_2 B'-\alpha_3=0$$

i.e.,

$$\alpha_1(A+a)+\alpha_2(B+b)-\alpha_3=0$$

in which

$$\alpha_1 A+\alpha_2 B-\alpha_3=0$$

so that

$$\alpha_1 a+\alpha_2 b=0 \qquad (1.2)$$

Similarly from (2)

$$\alpha_4 a+\alpha_5 b+\alpha_6 c=0 \qquad (2.2)$$

and from (3)

$$\alpha_8 b+\alpha_9 c+\alpha_{10} d=0 \qquad (3.2)$$

These equations are exactly analogous to (1), (2) and (3), except that they lack the independent terms; hence by analogy $b=\alpha_{16} a$, $c=\alpha_{18} a$, and $d=\alpha_{20} a$; in applications, these equations can be written down immediately following (1.1), (2.1) and (3.1). From these equations the effect of any proposed rounding-off in A can be seen; conversely, the rounding may be adjusted so that all the roots will be found to a specified accuracy, provided sufficient significant figures have been retained in the successive evaluations (1.1), (2.1), (3.1) to permit that accuracy.

Finally, if the values A', B', C' and D' are substituted in (4), the left-hand side is not likely to be exactly zero; suppose it is λ. Then

$$\alpha_{12} C'+\alpha_{13} D'-\alpha_{14}=\lambda$$

or

$$\alpha_{12}(C+c)+\alpha_{13}(D+d)-\alpha_{14}=\lambda$$

in which

$$\alpha_{12} C+\alpha_{13} D-\alpha_{14}=0$$

therefore

$$\alpha_{12}c+\alpha_{13}d=\lambda.$$

Now by analogy with (4) and (4.1), if

$$\alpha_{12}C+\alpha_{13}D-\alpha_{14}$$

becomes

$$\alpha_{21}A-\alpha_{22}$$

then

$$\alpha_{12}c+\alpha_{13}d=\alpha_{21}a.$$

Hence

$$\alpha_{21}a=\lambda \text{ and } a=\lambda/\alpha_{21}.$$

"a" should be less than half a unit in the place to which A was rounded-off to give A' and if so the whole of the values are reliable to the pre-determined accuracy. In practice when the coefficients in (1.1), (2.1) and (3.1) are worked out to a considerable number of significant figures, the value of λ/α_{21} will approximate very closely indeed to $A'-A$.

2a. We illustrate the method by a numerical example:—

Suppose

$$64A+15B-7568=0 \quad (1)$$
$$15A+56B+13C-5572=0 \quad (2)$$
$$13B+48C+11D-3528=0 \quad (3)$$
$$11C+60D-8190=0 \quad (4)$$

then

$$15B=7568-64A \text{ and}$$
$$B=504.5333-4.266667A \quad (1.1)$$
$$13C=5572-56\ (504.5333-4.266667A)$$
$$-15A=-22681.86+223.9334A \text{ and}$$
$$C=-1744.759+17.22564A \quad (2.1)$$
$$11D=3528-13\ (504.5333-4.266667A)$$
$$-48\ (-1744.759+17.22564A)$$
$$=80717.50-771.3640A \text{ and}$$
$$D=7337.954-70.12401A \quad (3.1)$$

Substituting in (4)

$$11\ (-1744.759+17.22564A)$$
$$+60\ (7337.954-70.12401A)-8190=0$$
$$\text{i.e., } 412894.85-4017.959A=0 \quad (4.1)$$
$$\text{hence } A=102.7623.$$

Further, $b=(-4.26\ldots)a$, $c=(17.22\ldots)a$ and $d=(-70.12\ldots)a$. If A' is taken as 102.762 the greatest error in any root will be d and will be of magnitude (70.12 . . .) (0.0003 . . .), i.e., less than 0.03; if taken as 102.76 the greatest error will be (70.12 . .) (0.0023 . . .), i.e., less than 0.2.

Taking $A'=102.76$, then $15B'=7568-6576.64=991.36$ and $B'=66.09$; $13C'=5572-1541.4-3701.04=329.56$ and $C'=25.35$; $11D'=3528-859.17-1216.80=1452.03$ and $D'=132.00$. Finally, $13C'+60D'-8190=278.85+7920.00-8190=8.85$ and by analogy with (4.1) $-4017.959a=8.85$, giving $a=-0.0022\ldots$ whilst $A'-A=-0.0023$. Hence the values found are reliable, no error exceeding 0.2.

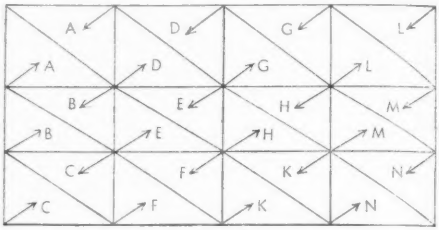


Fig. 3

3. For the frame of Fig. 3 assume redundancies A, B, C, etc., as in the fig. Then $\partial U_T/\partial A=0$ gives an equation in A, B and D only, $\partial U_T/\partial B=0$ one in A, B, C and E only, and so on, the equations containing in succession B, C and F; A, D, E and G; B, D, E, F and H; C, E, F and K; D, G, H and L; E, G, H, K and M; F, H, K and N; G, L and M; H, L, M and N; and K, M and N. From the first nine, we can express D, E, . . . N in turn in terms of A, B and C. Substituting for G, H, K, L, M and N in terms of A, B and C in the last three equations, we get three simultaneous equations to find A, B and C, say,

$$\beta_1A+\beta_2B+\beta_3C-\beta_4=0$$
$$\gamma_1A+\gamma_2B+\gamma_3C-\gamma_4=0$$
$$\delta_1A+\delta_2B+\delta_3C-\delta_4=0$$

These will be solved by any algebraic or numerical method. The values so found will, in practice, no doubt have to be rounded-off to, say, A', B' and C'. Exactly as in §2 equations can be written down by analogy giving d, e, f, etc., in terms of a, b and c and the rounding can be arranged to ensure any

desired accuracy in the values of D', E' . . . N' found by substituting A', B', C' and the others as they become available, in the first nine of the original equations. When the rounded values G', H', K', L', M' and N' are substituted in the last three equations, the left-hand sides will not be exactly zero, but will be, say, λ_1, λ_2, λ_3 respectively. Then by analogy with the above equations in A, B and C we have

$$\beta_1 a + \beta_2 b + \beta_3 c = \lambda_1$$
$$\gamma_1 a + \gamma_2 b + \gamma_3 c = \lambda_2$$
$$\delta_1 a + \delta_2 b + \delta_3 c = \lambda_3$$

From these a, b and c may be found and should be negligible to the standard of approximation used in rounding A, B and C to A', B' and C' respectively; and if so, the values found are reliable.

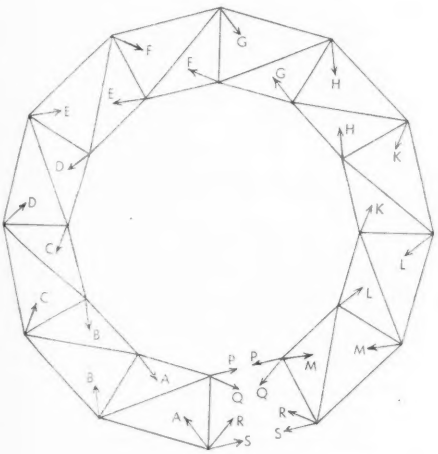


Fig. 4

4. For the diagonally braced " ring " of Fig. 4, there are three redundancies in addition to one from each counterbrace. P, P, Q, Q, R, R, S and S are taken as acting on the rest of the ring in drawing their force-diagrams so that the forces in the members will, in general, contain P, Q, R and S. But the forces due to the two A's alone will not go outside the panel involving A. Thus $\partial U_T/\partial A = 0$ will contain only P, Q, R, S, A and B, $\partial U_T/\partial B = 0$ only P, Q, R, S, A, B and C, $\partial U_T/\partial C = 0$ only P, Q, R, S, B, C and D, and so on. Thus all the unknowns can be expressed in terms of P, Q, R, S and A and five equations will have to be solved by algebraic methods. Four of these will come from $\partial U_T/\partial P = 0$, $\partial U_T/\partial Q = 0$, $\partial U_T/\partial R = 0$, $\partial U_T/\partial S = 0$, the remaining one from the last panel.

5. Application to the determination of secondary stresses in framed structures. The foregoing method also applies to the slope-deflection equations for the determination of secondary stresses in that type of framework which has rigid joints and is such that, if the rigid joints are replaced by pinned joints, a simply-rigid frame results, for which a force diagram can be drawn.

" One may assume without serious error that the secondary stresses are due to the bending of the members which takes place when the nodes of the stiff-jointed framework are forced into the position which the nodes of the pin-jointed framework would have taken up under the external load system. The latter can be found without difficulty by means of the Williot-Mohr deflection diagram." (Pippard and Baker, " Analysis of Engineering Structures," p. 219.)

If a number of bars meet at H (which it will be convenient to call the hub), θ_H, θ_A, etc., are the angles of rotation (clockwise) at H, A, etc., I_{HA} the second moment, l_{HA} the

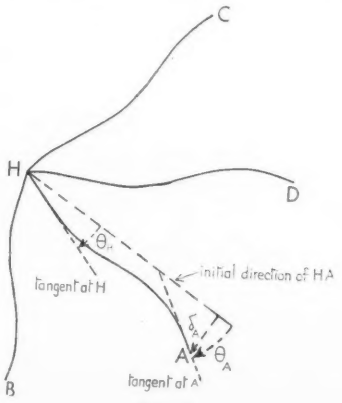


Fig. 5

length, of the bar HA and similarly for the other bars, E Young's modulus, δ_A the deflection at A, relative to H, perpendicular to HA, clockwise positive, and similarly for the other points, we have

$$\Sigma(EI/l)_{HA}(2\theta_H+\theta_A-3\delta_A/l_{HA})=0 \quad . \quad (13)$$

the summation extending over all the bars meeting at H. (See Fig. 5.)

The construction of the force-diagram for a simply-rigid frame usually depends on our being able to proceed from pin to pin, so that only two unknown forces are met at each pin in turn. Thus in the frame of Fig. 6 at

A	the unknowns are the forces in		AB	AC
B	,,	,,	BC	BD
C	,,	,,	CD	CE
D	,,	,,	DE	DF
E	,,	,,	EF	EG
G	,,	,,	GF	GH
F	,,	,,	FH	FK
H	,,	,,	HK	HL
K	,,	,,	KL	KM
L	,,	,,	LM	LN

As we proceed from point to point, one new letter occurs at each step, viz., C, D, E, F, G, H, K, L, M and N in turn.

Similarly in applying equation (13) with θ_A, θ_B, θ_C, etc., as the angles of rotation at A, B, C, etc., with

A	as hub, an equation results in the angles at		A, B, C
B	,,	,,	A, B, C, D
C	,,	,,	A, B, C, D, E
D	,,	,,	B, C, D, E, F
E	,,	,,	C, D, E, F, G
G	,,	,,	E, F, G, H
F	,,	,,	D, E, F, G, H, K
H	,,	,,	F, G, H, K, L
K	,,	,,	F, H, K, L, M
L	,,	,,	H, K, L, M, N

Step by step one new letter, i.e., one new unknown angle, appears exactly as the additional letter appears in the pinned structure. Hence we can express θ_C, θ_D, θ_E, etc., in succession in terms of θ_A and θ_B only; finally with hub at M and at N we get a pair of simultaneous equations to find θ_A and θ_B, which will probably have to be rounded-off to θ'_A and θ'_B.

If now we substitute in turn in the equations derived from (13) without simplification (i.e., before the coefficients of θ_H are added) we find θ'_C, θ'_D, etc., in succession and at the same time the values of the end moments may be written down, since the typical term in (13) is the end moment at H for the member HA. The last two equations, dealt with in the same way to complete the list of end moments, can be used to make the process self-checking, as noted in section 3.

5a. Comparison with the moment-distribution method. In the moment-distribution method, to distribute a couple M at a joint with r members, in proportion to the values of I/l for the members, requires one division of M by $\Sigma I/l$ and r multiplications of the quotient by I_1/l_1, I_2/l_2, etc.

In the present method, when applying (13) at the same joint, we have, when finding θ_C, θ_D, etc., in terms of θ_A and θ_B $(r+1)$ variables in the equation, involving $3r$ products and 3 quotients; when finding θ'_C, θ'_D, etc., and the end moments simultaneously as recommended, $2r$ or less products and one quotient. There are also two linear simultaneous equations to be solved for θ_A and θ_B and two for a and b to make the method self-checking.

In each method a number of sums require evaluation, a comparatively minor matter; in the distribution method there are also many divisions by 2, to find the clamping moment at one end of a member due to a couple applied at the other.

It may further be noted that if E is the same for all the members, we may regard $E\theta_A$, $E\theta_B$, etc., as the unknowns; if EI is the same for all members, $EI\theta_A$, $EI\theta_B$, etc., may be taken as unknowns; if all the values of l are sub-multiples of one, λ say (as in Fig. 6, where if the longer members are of length, λ, the shorter ones are of length $\lambda/\sqrt{2}$), then

θ_A/λ, θ_B/λ, etc., are convenient unknowns, and $E\theta_A/\lambda$, $E\theta_B/\lambda$, etc., if in addition E is the same for all members; if EI/l is the same for all members, then $EI\theta_A/l$, $EI\theta_B/l$, etc., are suitable unknowns; if all the values of EI/l are simple multiples of some one value $(EI/l)_1$, then $(EI/l)_1\theta_A$, $(EI/l)_1\theta_B$, etc., are

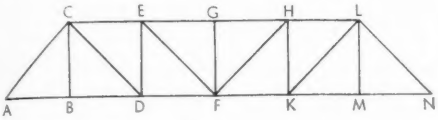


Fig. 6

suitable unknowns. Thus any simplification of the distribution of the moments in the moment-distribution method corresponds to a simplification of the coefficients in the equations in the present method.

It seems fair to suggest that the present method will involve less labour than five cycles of the moment-distribution method; further, it has the important advantage that it is self-checking; in the moment-distribution method it is necessary to repeat the calculation to ensure the absence of numerical errors.

6. Application to the equations for the rigidly jointed frame in a frame building. In the analysis of a plane frame consisting of s lines of vertical stanchions, rigidly fixed at the base, and rigidly connected by r horizontal beams, there are on the usual assumptions and where there is not symmetry of both load and frame about some vertical line, $r(s+1)$ unknowns. These may be taken to be (i) the angle of rotation at each joint, common to all the members at that joint: there are rs of these; and (ii) the sway of each line of beams relative to the beam below; of these there are r.

The slope-deflection method provides $r(s+1)$ equations to find these unknowns.

If A, H and B (to the right) are consecutive joints on a beam and C, H and D (upward) are consecutive joints on a column (Fig. 7), θ_A, θ_B, etc., the angles of rotation (clockwise) at A, B, etc., I_{AH} the second moment, l_{AH} the length, and ω_{AH} the uniform load-intensity respectively for the beam AH, and similarly for the other beams and columns, ${}_H\Delta_D$ the sway of D relative to H (to the right), ${}_C\Delta_H$ the sway of H relative to C (to the right), E Young's modulus, $\beta=2EI/l$, $\gamma=6EI/l^2$, and if we neglect the transverse dimensions of the beams and columns, we have

$$\beta_{AH}\theta_A+\beta_{BH}\theta_B+\beta_{CH}\theta_C+\beta_{DH}\theta_D+2\,(\beta_{HA}+\beta_{BH}+\beta_{CH}+\beta_{DH})\,\theta_H-\gamma_{CH}\cdot{}_C\Delta_H-\gamma_{DH}\cdot{}_D\Delta_H+(\omega l^2)_{AH}/12-(\omega l^2)_{BH}/12=0 \quad . \quad (14)$$

(Pippard and Baker, " Analysis of Engineering Structures," p. 193.) A small modification will allow if necessary for the transverse dimensions of the beams and columns; terms for concentrated loads and wind loads may also be included.

(a) If the frame and the loading are symmetrical about a vertical line.

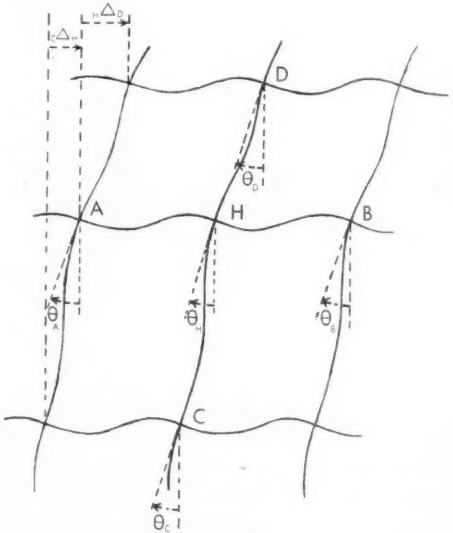


Fig. 7

In this case all the Δ's will be zero. The unknowns are then the rs angles only and the above equation can be applied rs times with every joint in turn as " H "; it will be convenient to call H the hub. When the

hub is on either outer column or on the uppermost or lowest beams there will, except at corners where there are but three, be only four angles. Elsewhere there are five. Thus the problem requires the solution of rs simultaneous linear equations, but each equation contains only 3, 4 or 5 unknowns.

It will be found that it is possible to express all the angles in succession in terms of the angles either on the left-hand stanchion or on the left-hand half of the lowest beam; one will choose whichever is the less; e.g., for any one of the four frames of Fig. 8, in terms of the angles at A, B and C; for applying (14) with hub at A, the equation resulting contains the angles at A, B and D only; with hub at B, the angles at C and E are also included and so on in succession with hub at C, D . . . N the equations are exactly similar to those in section 3. Three equations arise at the end to find θ_A, θ_B, θ_C, and from them the rounded values θ'_A, θ'_B, θ'_C. If the remaining angles are worked out from the unsimplified forms of (14), the end moments can be obtained at the same time by simple addition of the appropriate terms; thus the end moment at H for the bar AH is the sum of those terms with suffix AH; further, if the last three equations be dealt with similarly (and necessarily so dealt with to find the end moments, but not to find the angles) to find values of λ_1, λ_2 and λ_3 these may be used to find a, b and c and the method is self-checking.

It will be realised that increasing the number of stanchions with a given number of floors, or increasing the number of floors with a given number of stanchions, increases the successive-evaluation steps in direct proportion to their number, but gives no addition to the number of simultaneous equations to be solved by algebraic methods.

(*b*) If the structure and/or the loading is not symmetrical. In this case there will be r equations in addition to the rs equations of the type quoted, (14).

If L and U are consecutive points on a stanchion (upwards), I_{LU} the second moment of the stanchion LU, h its length, θ_L and θ_U the angles of rotation (clockwise) at L and U respectively, and ${}_L\Delta_U$ the sway (to the right) of the floor U relative to the floor L, then

$$h\Sigma I_{LU}(\theta_L+\theta_U)-2_L\Delta_U\Sigma I_{LU}=0 \quad . \quad (15)$$

where the summations extend to all the stanchions in the storey.

It will now be possible to express all the angles in terms of the angles on the left-hand stanchion *or* on the lowest beam, plus the r Δ's, and the number of simultaneous

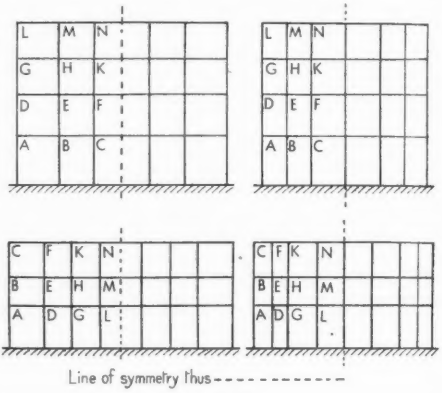


Fig. 8

equations to be solved at the end will be double the number of storeys *or* the number of storeys, plus the number of stanchions in a storey, whichever is the less.

7. If the diagonal braces in Fig. 2 are of wire and the other members are bars or tubes, so that the elastic constant for a brace is a large multiple of that for a bar, we get a set of equations for which the foregoing method is not advisable. Thus if the panels are square and the elastic constant for each wire is nine times that of each longitudinal or transversal, the equations become

$$40A+B=\epsilon_1$$
$$A+40B+C=\epsilon_2$$
$$B+40C+D=\epsilon_3$$
$$C+40D=\epsilon_4$$

where the ϵ's depend on the external loads. Thus there is one large coefficient in each

equation, for successive unknowns in successive equations. Such a set of equations is very suitable for solution by iteration. Starting with

$$B \fallingdotseq \epsilon_2/40,\ C \fallingdotseq \epsilon_3/40,\ D \fallingdotseq \epsilon_4/40$$

successive approximate values are calculated in turn for A, B, C, D, A, B, and so on, using new values as soon as they become available. After a very few cycles, the same values, to the three or four significant figures required by engineers, will be found in successive operations, which proves them to be the correct values.

GRAPHICS *of* WORLD AVIATION

by

A. J. Dilloway

A. J. Dilloway has been, since 1935, on the Staff of the Geographical Section, General Staff, War Office. This section is responsible for the production of all the special maps and charts required by the Air Ministry. He has carried out researches on the theory of cartography, particularly for long distance navigation and a paper by him was published in the Journal in 1942.

TO claim that communications have unified our world is by now to voice a truism. Within the span of a generation we have thrust headlong into an age of transition and readjustment, the definitive trend of which is towards a world-wide mobility of goods, ideas, and the citizens who produce them. The role of the air route in this process is no longer a matter of dispute, and it is clear that the time has come to consider certain technical questions which underlie any detailed scheme for a truly international network of airways.

Now whether we think in terms of geography or of navigation, our view of this new environment finds practical expression in a world of two dimensions. But whereas in the past our graphical planning dealt very largely in terms of " straight lines " on the flattish earth of a regional scale of operations, the planning and navigating of world airways requires a greatly expanded technique for the accurate expression in two dimensions of concepts of distance, direction and position on the spheroidal surface of the earth. In this paper, therefore, we have to discuss the means available to provide a graphical basis for the planning and operation of a system of air highways on a world scale. Although the main outlines of the subject are founded on well-established cartographic theory, much of the material now presented is described for the first time. In many respects, the present study supplements and extends a systematic theoretical treatment of great circle problems already attempted in an earlier paper.[1]

Paper received February 15th, 1945

General Considerations

Any forward-looking discussion of the graphics of air navigation has first to take account of certain basic facts or assumptions which follow from the present levels of technical achievement on the one hand, and of world organisation on the other. As a preliminary to dealing with such facts, it is necessary to remember that some enthusiasts see in the latest developments, which cannot yet be discussed, a virtual abolition of the old navigation, and a corresponding lessening of the dependence on the air chart as an essential part of the navigator's equipment. At present it is fairly safe to assume that in the immediate future most of the *fundamental* needs and methods will remain largely unaffected. When one remembers the wide range of conditions on potential routes, this viewpoint would seem to be well justified.

[1] A. J. Dilloway: Cartographic Solution of Great Circle Problems, *Jour. Roy. Aer. Soc.*, Vol. 46, 1942, pp. 4-31.

First, then, among the basic facts to be considered is that of a continuing increase, by previous civil standards, in the speed, range and size of aircraft, and in practicable altitudes for flight. These considerations are certain to initiate a growing demand for operational maps covering wider ranges on smaller scales, and with a tendency towards route maps as opposed to regional sheet-lines. This latter trend will be supported by the introduction of technical aids like radio-location and television, and may possibly encourage the adaptation of such strip maps to devices based on optical projection.

The prospect of increases in speed, range and altitude is leading also to the emergence of a very real, if somewhat over-optimistic, attempt at a world outlook, and has brought about an insistent demand for special planning maps to facilitate the study and measurement of great circle relations. The first rush of " paper planning " has already been countered by more sober estimates of an effective initial performance for great circle flying somewhere in the region of 2000 miles at 200-plus miles per hour. It is salutary to remember certain other facts which, at the present stage of development, serve to temper an unrestrained enthusiasm for the great circle. First among these may be mentioned difficulties of terrain and of meteorological conditions. Much more detailed knowledge of weather conditions—and particularly of wind velocities at various altitudes—is needed before the route requiring the least expenditure of time and energy can easily be laid down. Great circle distance is only one of the factors determining the length of a journey by air,[2] and recent observations of cloud movements suggest that, even at high altitudes, conditions are by no means as stable as is often supposed. With these facts in mind the comparatively small advantage of the great circle as compared with the loxodrome is seen in a new light. Perhaps this advantage is further offset by considering the practical importance of those existing routes which link up established centres of population.[3] Finally, and as an index of the *absolute* importance of the great circle as a traffic artery, we have to remember that the actual volume of such traffic is limited, though perhaps to a decreasing extent, by the high cost of the increased speed of transit, measured in terms of energy consumption, when compared with those of other methods of transportation. Nevertheless, the possibilities of new methods of propulsion alone are sufficient to show the future importance of routes approximating to the great circle.

The two-fold character of civil flying has next to be borne in mind. A network of carefully prepared air highways, carrying both passengers and freight and tending where possible to follow great circle routes across the world, will be contrasted with a greatly increased activity in both public and private short-range air travel in every direction. This last consideration points to the need for comprehensive series of *regional* air charts designed to meet a wide variety of requirements.

Finally, the question of the co-ordination of all this activity leads to the vital concept of a super-national commission for the development of world transport, and underlines the fact (long since recognised in theory) that such a series of charts should be planned and constructed as a whole, and to a standard pattern. This, of course, implies an international scheme and links up with the obvious need for a world synthesis and control of the various technical

[2] For a general treatment of air-route problems from the geographical aspect, see the discussion, The Geography of Post-War Air Routes, *Geog. Jour.*, Vol. 103, 1944, pp. 89-100; and for a magnificently exhaustive treatment from the technological standpoint, see E. P. Warner: Post-War Transport Aircraft, *Jour. Roy. Aer. Soc.*, Vol. 47, 1943, pp. 186-254.

[3] Feeder routes branching north and south from the main great circle routes may of course help to cancel out this criticism.

resources required for an all-embracing system of airways.

So much for general considerations of aeronautics and politics. The conclusion emerges that three main needs have to be satisfied. In addition to an appraisal of the graphics of world geography, and of ways of providing for the accurate study and planning of great circle relationships, we have to budget both for standard world series of navigational charts and for a series of strip charts to cover the more important routes. Finally, there is the need for such additional aids to long-distance navigation as can be provided.

The Basic Variables of Map Projection

This introductory section is a condensed summary of certain fundamental ideas in cartography—particularly those of interest in the present context. It is included with a view to completeness of treatment and with the further object of linking up the properties of certain relatively new types of map with those already well-known to the navigator. The section could be ignored by the specialist, although Fig. 2 may be of interest.

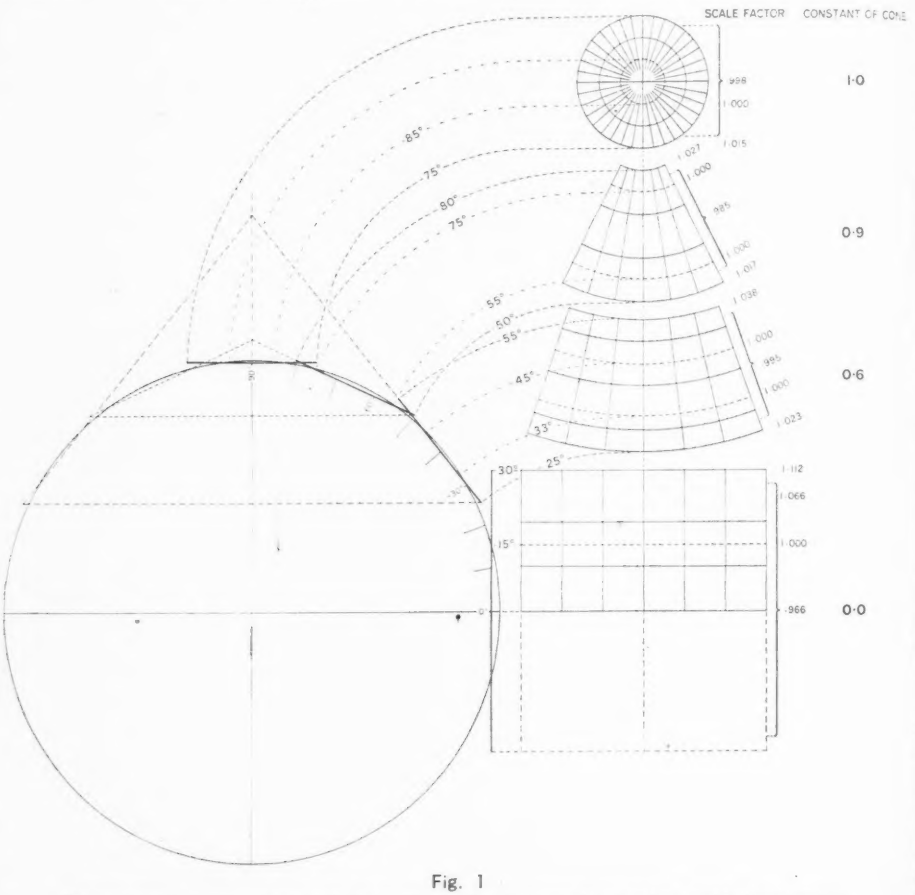


Fig. 1
Diagrammatic representation of zones of cylindrical, conical and polar zenithal projection.

The need for alternative methods of projection arises from the basic difficulty that the surface of the earth, in common with

that of any other spheroid, cannot be developed, or expressed without distortion in a two-dimensional form. In the three main groups of map projections that can be distinguished, this limitation is partially overcome by methods which are equivalent to considering the surface of a model sphere, or "reduced earth," to be projected on to one of three types of developable surface—the cone, plane or cylinder. The second of varying either the form of the developable surface, its relation to the surface of the sphere, or the position of the point from which the spherical surface is imagined to be projected on to the plane surface—that is, the point of projection. The first of these variables—the type of developable surface—will decide the general appearance of the network of meridians and parallels. Fig. 1 shows in a diagrammatic form the derivation

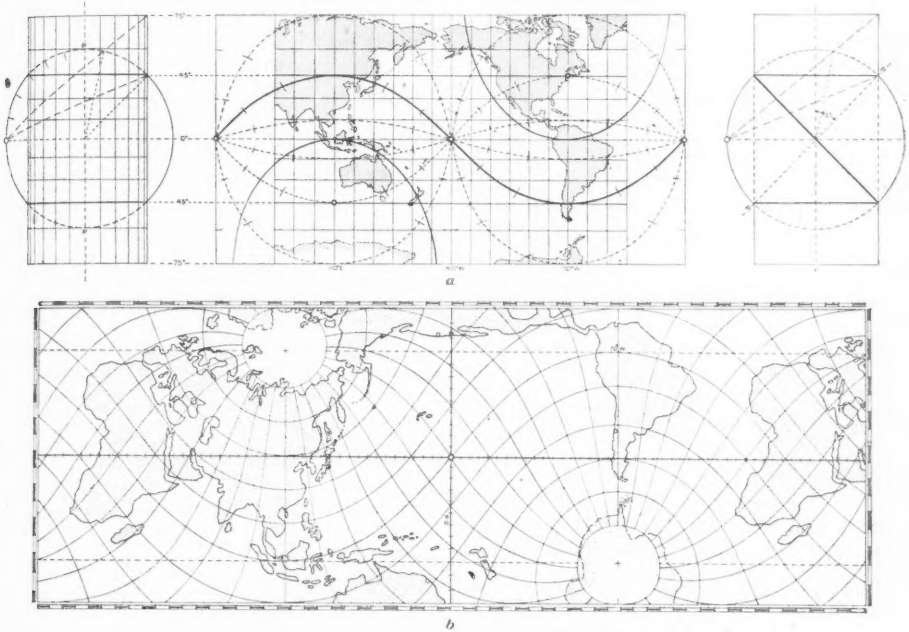


Fig. 2
GALL'S CYLINDRICAL STEREOGRAPHIC PROJECTION.
(*a*) Normal projection with transverse network superimposed. See also the traces of the axes and standard small circles of the oblique projection.
(*b*) The derivation of both maps is shown diagrammatically, the point of projection being assumed to move around the reduced earth.

these types of surface may include both the simple plane and any compound assemblage of planes such as is found in the cube, dodecahedron, icosahedron or any other regular solid that can be circumscribed about the model earth. In this method of representing the surface of the globe in two dimensions (for the use of a cone or cylinder is only an intermediate step towards this end) the resulting map picture may be varied by of three familiar types of projection—cylindrical, conical and polar zenithal—which result from the use of the corresponding types of surface of reference. It may be observed that both plane and cylinder are merely extreme variants of the cone, the nature of which within these limits can be defined by the ratio between the angle at the apex of the cone (when developed) and four right angles. This relationship—known as the

constant of the cone—can obviously vary between 0 and 1, and is illustrated in the figure.

The second variable—the relation of the surface of projection to that of the model sphere—possesses two components. First, the plane, cylinder or cone may be tangent to the sphere at a point or along a great or small circle; or, alternatively, any of them may be imagined to intersect the surface of the sphere along small circles. Thus, in Fig. 1 the various planes of reference are supposed in each case to intersect the surface along parallels of latitude, shown dotted in the corresponding networks or graticules. Secondly, these relationships may obtain at the equator, at either pole, or at an intermediate latitude anywhere on the earth. While polar and equatorial cases remain the more common, oblique projections have become increasingly important during the last few years, and will be considered in greater detail below.

Finally, we have as a third variable the point from which one surface is projected on to the other. This may be considered to vary between a position at the centre of the model sphere and one at an infinite distance from it. The nature of the scale distortion in the resulting map will vary accordingly. It should be emphasised that, with the exception of the constant of the cone, these concepts and relationships are of no practical value in the construction of maps, and are merely convenient ways of visualising the mathematical properties of some of the useful methods of representing the surface of the earth upon a sheet of paper. In any case, many projections have a mathematical basis which cannot properly be interpreted in this way. This of course is true of the two projections most familiar to the air navigator, neither of which is a projection in the geometrical sense.

It may be worth while to consider very briefly certain basic properties of and resemblances between the three classes of network shown in Fig. 1. In the first place, each is of a normal and familiar kind, *i.e.* the axes of the cones and the cylinder of reference, and the centre of the plane of reference, are all coincident with the axis of the reduced earth. It follows that, for any single type of map, the scale value will be constant, though not necessarily true, along each parallel; while the variation of scale along the meridians is the same for every meridian of a given projection. Turning first to the cylindrical network, one may note the source of differences between the various members of the class. All cylindrical projections in which the axis of the cylinder of reference coincides with that of the earth comprise, first, a series of straight, parallel and equidistant meridians, always at their true distance apart at the equator—unless, as in the example shown, the spacing is reduced in order to preserve correct scale along two " standard parallels." Since the meridians are in all cases exactly similar, therefore, the differences between cylindrical projections depend entirely on the spacing of the orthogonal series of straight parallels of latitude. According to the purpose in view, the scale along the meridians can be stretched or compressed by varying (where the analogy is practicable) the position of the point of projection. It should be noted, however, that where the N.-S. stretching is arranged to give orthomorphism—that is, where the scale at every point is made the same along the meridian as along the parallel, giving theoretically " true shape "—it is no longer possible to think in terms of optical projection. In both cylindrical and conical projections of this kind the graticule is rather to be considered as in the nature of a mathematically consistent transcription of the earth's surface.

Finally, cylindrical projections need not be confined to the equator as an axis of symmetry. Oblique (and transverse) projections, based on a cylinder which may be in contact with the earth along *any* convenient great circle, should prove extremely impor-

tant as aids to long-distance flying along prescribed routes.

The straight, radiating meridians of the conical network are also essentially similar for each projection, differing only in the angle included between them, which in a given case depends approximately on the true convergence between meridians on the earth at the middle latitude of the area to be mapped. The differences between the various conical projections have therefore to be obtained mainly by varying the distances between the concentric circular parallels and thereby stretching or compressing the scale along the meridians according to the properties required. Conical projections are of great value for world air charts when they are constructed in the normal manner, with the imaginary " secant " cone of reference cutting the reduced earth along two standard parallels of latitude. Oblique, or even transverse projections are equally possible, and the former are of use in the mapping of areas where the configuration favours small circles of the earth as " lines of strength "; but they would seem to have little relevance to air routes, unless it should happen that the general alignment of a route connecting a number of points of call approximates to a small circle.

Zenithal projections are of great and increasing importance for navigation, particularly as auxiliaries and for special purposes. The polar cases of certain zenithals, with their straight meridians radiating at the true longitude interval, lend themselves very easily to adaptation for trans-polar flying. Once again the differences between the various methods of projection are secured by varying the distances between the concentric circular parallels, and thereby adjusting the scale along the meridians. In the example shown in Fig. 1 the scale is also reduced to give a standard parallel at latitude 85°N. Although the more generally useful cases of zenithal projections—those centred at the equator or at an intermediate latitude —differ markedly in appearance from the polar case, they retain for the point chosen as centre exactly the same properties, so far as scale distortion, true bearings and straight representation of great circles are concerned, as are preserved at the pole when this is made the centre of the map. This point is well shown in Fig. 12. Certain special uses of such oblique zenithal projections are considered in detail below.

These, then, are the simple variants from which the more generally useful kinds of map may be built up. Many new combinations have been devised quite recently, as aids in dealing with world problems of a new magnitude and urgency. One such example offers a particularly good illustration of the use of various ideas brought out in this section. It offers also a good opportunity to illustrate a general principle governing the representation of great circles on each of the types of map so far discussed.

Suppose a projection to be required to show the world relationships of the Pacific area.[1] As is brought out in Fig. 2*a*, this vast ocean trends approximately north-west to south-east, with its centre of gravity roughly in longitude 160°W. on the equator. Ignoring for the moment everything but the graticule, the figure is drawn on Gall's Stereographic projection, a cylindrical projection of the true geometrical or " perspective " type, derived as shown. The cylinder of reference intersects the reduced earth along two standard parallels (45° N. and S.), and the equator thus forms the main axis of the map. Suppose now the same cylinder of reference to be used, but to be tilted at an angle of 45°, so that the map is symmetrical about a great circle inclined at 45° to the plane of the equator. Further, suppose this great circle to intersect the equator in the centre of the Pacific, at longitude 160° W. Fig. 2*b* shows the map which will result. It should be noted that the cylinder has been assumed to encompass the earth one and a quarter times, with a consequent duplication

[1] The treatment of this question which follows is an extension of the author's part in a discussion on the Map of the Pacific. See *Geog. Jour.*, Vol. 100, 1942, pp. 65-72.

of Europe and Africa; and to cover only 60° of angular distance north and south of the main axis (henceforth referred to as the generating axis). Along this axis, and perpendicular to it, the properties of the map are exactly as before. The two standard parallels become small circles at an angular distance of 45° from the generating great circle, and remain straight lines. They are shown as pecked lines in the figure. The scale properties of the map are brought out by the graduation, at 5° intervals, of the two straight axes passing through the centre of the Pacific. The shorter is the great circle through San Francisco and Brisbane, and all lines parallel to it are also great circles, the variation of scale along each being exactly the same as along the meridians of the normal projection (Fig. 2*a*). Lines parallel to the longer axis (also, of course, a great circle) are small circles with scale constant along each but incorrect, except along the two " standards."

The projection of any other great circle on the map can be laid down with ease by making use of a principle that can be applied with equal facility to cylindrical, zenithal or conical projections. To determine on a globe the great circle joining two points, it would be possible to rotate the points about a diameter of the globe (keeping them in the same relation to each other) until they both fell on the same meridian. The section of meridian joining them would then be the trace of the great circle required.[5] An equivalent operation can be carried out on any cylindrical map by constructing as a transparency the projection of a series of great circles passing through two nodes or poles, these poles being situated on the generating axis of the map, and 180° apart. Keeping the traces of this axis (on map and overlay) in coincidence, the transparency can be moved to bring any two points on the map on to a common great circle on the overlay. This latter will be the trace of the great circle course between the points. If now the projections of a series of orthogonal small circles are added to the overlay, we obtain what amounts to a transverse case of the projection, *i.e.* one in which the generating great circle of the cylinder passes through the poles of the model earth. A transverse system of this kind is shown superimposed on the normal projection in Fig. 2*a*. In effect it is the projection of a series of great circle courses, each with a series of intercepts giving a scale for the measurement of great circle distance. Combining these ideas with the properties of cylindrical projections already deduced, the following general conclusions may be drawn. First, a transverse network may be used in this way with any example of the same projection—normal, transverse or oblique—provided the scale along the generating great circle is always the same. Secondly, the method may be applied to any projection of the cylindrical class.

This simple and accurate method of laying down courses is perhaps better known in its application to zenithal projections. the only difference being that, on the zenithal map, movement of the great circle overlay will take the form of a rotation about the point of tangency, or centre of projection. For the map this centre of projection may be chosen at any latitude: for the transparent overlay it must be a point on the equator, so that the two nodes of the system of great circles are sited on the circular edge of a hemisphere. Thus the overlay is really an equatorial case of the particular projection employed.

When the method is applied to conical projections, the overlay becomes a transverse case of the projection, with the axis of the cone of reference coinciding, not with the polar axis of the earth, but with an axis passing through the equator. Again the overlay is rotated about a common centre, which this time will be the traces of the respective axes of the two cones of reference.

[5] For a full treatment, see Dilloway, *op. cit.*, *Jour. Roy. Aer. Soc.*, 1942.

This sketch of the question of great circle representation completes the background of essentials needed to treat most of the cartographic problems posed by the new range of world flying, and leads conveniently into the main questions with which this paper has to deal. These may be summarised under the following heads:

1. Graphical aids to the planning of world routes.
2. Design of a world series of regional charts.
3. Design of special route charts.
4. Special aids in pre-flight determinations.

1. GRAPHICAL AIDS TO THE PLANNING OF WORLD ROUTES

Under the stimulus of radio communication and air travel, the measurement of world-wide relationships of distance and direction has become an important matter, and has given an entirely new slant to the hitherto "intractable" problem of the flat map. The uses for this purpose of many different methods of projection have been explored in an earlier paper in this journal.[6] If the objective in such a search had been merely a good visual impression of the globe, the list of projections there treated could have been multiplied many times over. Thus, from the wealth of entirely new systems of representation, it will suffice to mention the current vogue in world maps made by a construction equivalent to "peeling" the earth from the pole like an orange, the segments of such peeled projections being arranged in a variety of pleasing developments. If facilities for the accurate measurement of distance, direction and course have to be incorporated in such a world map, however, the choice is limited by a variety of practical considerations to certain members of the cylindrical and zenithal classes.

Perhaps the earliest and best known, but not the most useful solution of this problem is that afforded by gnomonic projection from the centre of the sphere on to the faces of a circumscribed cube, dodecahedron or icosahedron.[7] The points of tangency of the faces of these solids can be chosen to satisfy any required arrangement of terrain, while continuity along world routes is also possible, since faces can be "developed" in any order. When the cubic development is used the straight sections of any great circle can be continued across the various faces by the application of fairly simple rules, and the retention of the normal zenithal properties about the centre of each face allows the method of rotation to be applied to distance measurements in respect of each of the four sections of a continuous route. Bearings, however, will not remain true, and the distortion at the edge of each face is an awkward handicap. Maurer[8] has varied the cubic development, using an assorted series of six rectangular planes or "faces" in order to show particular configurations to the best advantage. Turning to the icosahedral development,[9] this provides the greatest possible number (twenty) of regular polygonal faces, and thereby minimises distortion, but at the expense of the convenient protraction and measurement of great circles. Zenithal projections other than the gnomonic could clearly be treated in the same way, though without any particular advantage being gained. While the cubic development, then, may be of use for certain purposes, the value of icosahedral and other polygonal developments depends on their capacity to

[6] Dilloway, *op. cit.*

[7] R. Buckminster Fuller has produced a gnomonic world map by dividing the surface of the sphere into fourteen segments formed by four intersecting great circles, and projecting these as eight equilateral triangles and six squares which can be combined in any order. See R. Buckminster Fuller: Fluid Geography, *American Neptune*, Vol. 4, 1944, pp. 119-136.

[8] H. Maurer: Ebene Kugelbilder, *Petermann's Geog. Mitt.*, Erg. 221, 1935.

[9] Irving Fisher: A World Map on a Regular Icosahedron by Gnomonic Projection, *Geog. Rev.*, Vol. 33, 1943, pp. 605-619.

bridge the gap between the model globe and the flat map, and thus to provide a good general impression of the world.

Another device for simplifying great circle measurements between any two points on the earth is an application of certain properties of cylindrical projection in a manner already described. Mr. A. R. Hinks[10] has constructed a series of oblique Mercator maps based on generating great circles chosen to give varied and useful representations of as large an area as can conveniently be covered by this projection. The series includes a transverse network with the parallels numbered in thousands of kilometres. This is used for measurements of distance and track according to the method already described. No particular provision is made for the measurement of bearing, but the projection allows of approximate measurements within one half a degree or so. All maps are drawn to the same longitudinal scale, and are confined by the well-known limitations of the Mercator to an angular distance of some 70 degrees on each side of the main axis. This allows a cover of some 94 per cent. of the total surface. For the same reason, the traces of some of the great circles will travel to infinity and back, and will therefore be incomplete. This does not affect the accuracy of the method, but it does necessitate a *series* of projections if the whole area, including the poles, is to be covered completely.

This last disadvantage is not shared by Mr. O. M. Miller's use of the same principle.[11] In this case a conventionally modified Mercator, not greatly different in appearance from Gall's projection, is used to make a normal cylindrical map, thus allowing the poles to be included without extreme distortion. A world map of this type, together with a transverse grid for laying down great circles, has already been constructed for the U.S. Department of State at a scale of 1:50,000,000.

A notable disadvantage of all such devices based on cylindrical projection is the lack

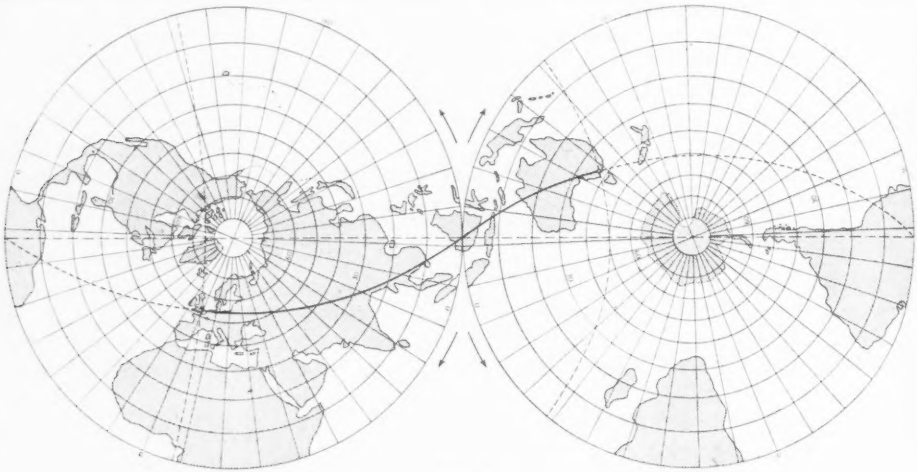


Fig. 3
Geared stereographic hemispheres in polar projections (transparencies).

[10] A. R. Hinks: Maps of the World on an Oblique Mercator Projection, *Geog. Jour.*, Vol. 95, 1940, pp. 381-383; Map Projections and Sun Compasses—III. More World Maps on Oblique Mercator Projections, *Geog. Jour.*, Vol. 97, 1941, pp. 353-356; and see also in The Geography of Post-War Air Routes, pp. 93-95.

[11] O. M. Miller: Notes on Cylindrical World Map Projections, *Geog. Rev.*, Vol. 32, 1942, pp. 424-430.

of provision for accurate and convenient measurement of bearing. This difficulty can largely be avoided by a method outlined by the present writer in the course of a discussion on the Map of the Pacific,[12] and here figured and described for the first time.

The principle of the device is very familiar, and can be applied to several projections of the zenithal group. Its links with the stereographic extend over several centuries, examples being found on some of the astrolabes of the early navigators. The originality of the present method of use lies in its application to measurements over the entire globe. The device consists, first, of two similar circular hemispheres drawn in stereographic projection, with their points of tangency at opposite ends of a diameter of the earth. For practical purposes these two centres are best situated as shown in Figs. 3 and 4, either at the poles or on London and its antipodal point. The advantages of the first of these alternatives are obvious—straight meridians and true relationships between important centres in the northern and southern hemispheres. Equally valuable advantages are gained by the second alternative, since all routes through London become straight lines inclined at their true bearings, while the use of this centre gives an optimum arrangement of continental masses, and thus ensures a minimum of interruption. In either case the two hemispheres are constructed as transparencies, and these are placed tangentially so as to rotate about the respective centres. They should also be geared together, so that corresponding points on the edge of each will always coincide. These two transparencies rotate over the second component, a base consisting of a two-hemisphere grid of great circles and great circle distances (Fig. 5). It will be seen that this is really made up of two equatorial networks of the same projection, drawn to the same scale and also placed tangentially. The trace of the great circle passing through any two points on the earth is determined at once by turning the transparent maps until the terminal points of the route lie on the same great circle curve on the base. As is shown diagrammatically in Fig. 3, this curve will also pass through the common point of tangency. Distances in either hemisphere are measured on the base

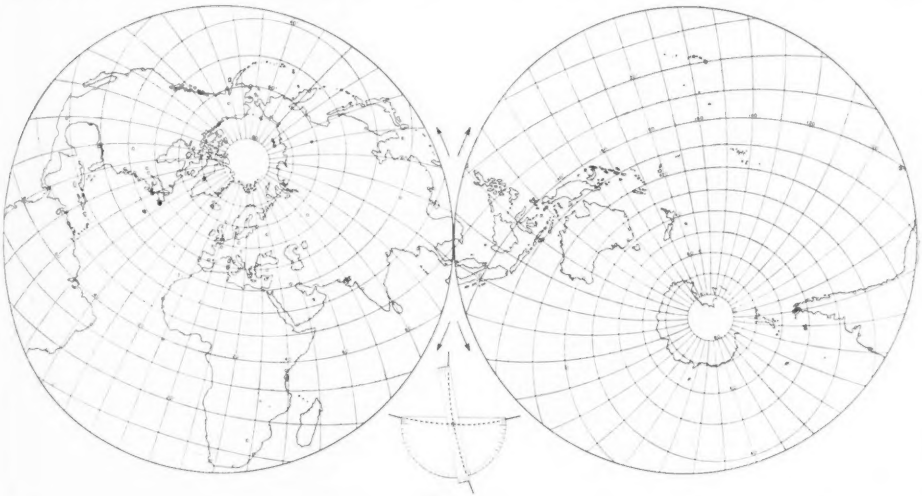


Fig. 4

Geared stereographic hemispheres centred on London and its antipodal point (transparencies).

[12] *Op. cit.*, pp. 68-69.

from this common point, and are added to give the total distance when parts of the route lie in both hemispheres. It is a peculiarity of stereographic projection that *all* circles, great or small, are projected on the map either as arcs of circles or as straight lines. Moreover, the angles included between such great circle arcs are in all cases truly shown. This means that bearings included between any route and the meridians through which it passes can be measured with complete accuracy by employing a simple device to define the tangents to the arcs at their points of intersection (Fig. 4). Although each set of hemispheres gives a complete world cover, it would be an advantage if the two versions could be used interchangeably with the same base, thus making available two (or more) orthomorphic representations of the world and allowing a choice of map according to the purpose in view.

Thus, in spite of the great variety of ingenious world projections, very few are available for purposes of accurate measurement. While the cylindrical maps have the advantage of simplicity in use so far as continuity of representation is concerned, the method last described offers facilities for simple and accurate determination of all quantities needed to define any great circle route completely. When the device is properly constructed, with the gearing allowing very rapid alignment on the great circle, it would seem to provide quite comfortably for the initial planning of world air routes.

2. DESIGN OF A WORLD SERIES OF REGIONAL CHARTS

In planning a series of air charts for general use, the more important considerations bear on the nature of:

i. The straight line course on the map.
ii. Facilities for plotting positions by co-ordinates.
iii. The representation of convergence.
iv. The distribution of linear and angular distortion.
v. The assemblage of sheets to give satisfactory world coverage, with overlaps.

With these criteria in mind, it may be instructive briefly to review the various

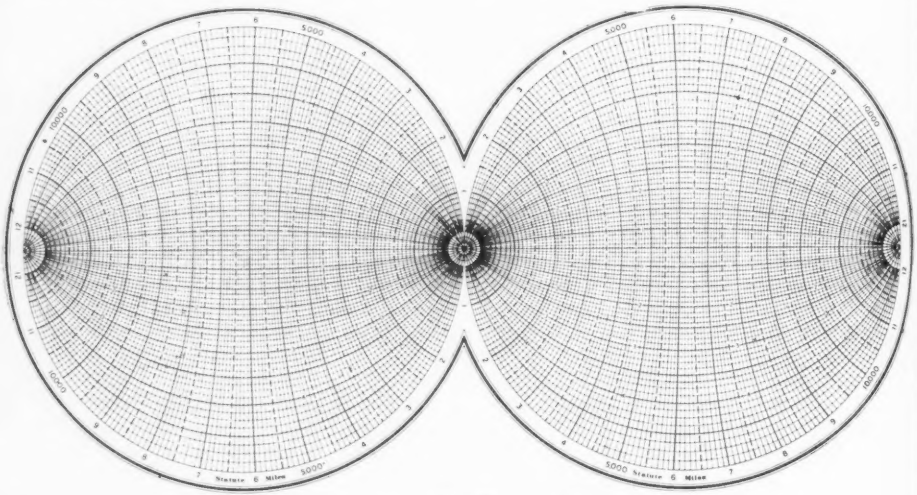


Fig. 5
Basic grid of great circles and great-circle distances for use with geared stereographic hemispheres.

solutions that have been or might be applied to this problem.

The attempts so far made to produce a world series of regional air charts have relied almost entirely on two contrasting types of representation. The first, now very popular in the United States, is illustrated diagrammatically in Fig. 1. Bands of latitude, extending round the earth, are covered by overlapping zones of cylindrical, conical or zenithal orthomorphic projection respectively, the standard parallels of each so chosen as to confine scale variation within narrow limits, and to ensure that the great circle track is everywhere approximated by a straight line, which will be inclined to each meridian at roughly the true bearing. Such a system has many obvious advantages. It is admirably adapted to give world coverage, since the entire series is continuous in longitude, while each zone can be subdivided into as many overlapping sheets as are required. Moreover, the breadth, or latitudinal extent of each zone, can be varied according to the scale and standard of accuracy required. Finally, the meridians are straight lines, and the orthomorphic networks provide for a direct-plotting system based on the great circle and needing no special correction. Such a system is particularly well suited to short- and medium-range navigation, in which map reading plays a major part.

Schemes for a small-scale series on these lines are sufficiently numerous to offer a number of good examples. One of the earliest was the proposal of Driencourt and Laborde,[13] who in 1932 suggested the use of Mercator's projection up to latitude 15°, with zones of Lambert's Conical Orthomorphic from 10°-40°, 30°-60° and 50°-80°, ending with polar stereographic maps from 75° to the pole. The scheme shown in Fig. 1 is intended for use with these same projections, and was worked out by a group of American cartographers brought together by Lieut.-Commander P. V. H. Weems.[14] A series of blank graticules was designed to cover the entire range of latitude at a mean scale of 1:5,000,000, and to serve as a base from which quantities of distance, bearing and great circle track could be read without correction when terminal points had been plotted and joined by a straight line. Weems has given examples to show how closely straight line quantities taken from these four overlapping charts, and measured along distance scales based on the scale factors, approximate to the true values obtained by calculation. The use of Mercator (and, therefore, the rhumb line course) as far north or south as latitude 30° is justified by the insignificant advantages of the great circle below that latitude. These base charts are intended to be used by the marine navigator as adjuncts to the Mercator chart; and, if generally adopted, would mark a first step towards the greater flexibility associated with navigational technique in the air.

The most notable example of a scheme of this kind is that now being carried through in the United States. The scale is 1:1,000,000, and each of the zones of cylindrical, conical and zenithal orthomorphic projection is subdivided, in latitude as well as in longitude, so as to provide a series giving a complete cover of the earth's surface in many hundreds of sheets, each being surrounded, according to a novel system, with a complete cover of skeleton overlaps. This series is designed specifically for use in the air, and is one of the most ambitious tasks yet undertaken by the cartographer.

At first sight it would appear that the advantages for air navigation of a series based on zones of orthomorphic projection, with straight meridians, closely fitting overlaps, minimised scale distortion and approximately true representation of bearing, dis-

[13] L. Driencourt and J. Laborde: Traité des Projections des Cartes Géographiques (4 Vols.), Hermann, Paris, 1932. Air maps are treated in Vol. 2, pp. 97-105.

[14] P. V. H. Weems: Marine Navigation, D. Van Nostrand Co., New York, 1940, pp. 24-26, 114-118.

tance and great circle track, would heavily outweigh any others that could be offered. To a very large extent this is true. But, while navigational technique depends at all on lines of position laid down during flight, the extent to which the air chart lends itself to the solution of such problems remains a major test of its usefulness. At the present time the only possible rival of the conical system is the cylindrical orthomorphic or Mercator; and debate on the merits of each for world mapping has continued, though with diminishing intensity, to produce valid arguments on both sides. The clear-cut gains of the conical system in uniformity of representation are set against the traditional simplicity of the rectangular orthomorphic graticule, with its ease of plotting and angular measurement, its perfect matching of sheet edges and overlaps, and the constant relationship it retains between great circle, rhumb line and iso-azimuth. All these properties are valuable in plotting position lines, as is the opportunity to reproduce mechanically the movement of small circles of equal altitude. On the other hand, that most famous attribute of the Mercator, the rhumb line of constant bearing, is really a misnomer so far as the magnetic compass is concerned.

There are two further points bearing on this question. One is the query as to how long and to what extent astro-navigation, on which Mercator's usefulness largely depends, will continue in use alongside the new methods recently developed. At the present time we are passing through a stage of transition, when almost contradictory policies, in the matter of navigational training and practice, are being pursued at the same time. The wide variety of flying conditions likely to exist for some time to come may be expected to continue this period of transition into the immediate future, and on this score alone will justify the continued production of Mercator charts. In any case, the demands made by the newer methods are such as to underline those very properties that have proved of value in the systems of projection already employed.

The second point to be borne in mind concerns the false antithesis between converging and rectangular meridians. As long ago as 1929, Admiral (then Captain) Tonta showed clearly, in the course of three papers,[15] how rectangular axes of measurement could be used on both polar and normal conical maps for purposes of navigation. It is unnecessary to anticipate the fuller treatment of this question given later, when some new approaches to the subject are explored in detail. It will suffice to observe here that the simplicity and convenience of an uniform series of rectangular orthomorphic charts can be said to justify their continued use as adjuncts to *any* series of conical sheets, however designed.

There are certain precedents for a world series of air charts on the Mercator system. Thus the proposals of the original International Commission for Air Navigation included two series on this projection. The basic map, on a scale of 1 : 10,000,000, was intended to cover the earth in 16 sheets, with eight quarter sheets on the stereographic to cover the polar caps. Several sheets of the general map on the scale of 1 : 3,708,758 (3 centimetres to 1° longitude at the equator) were actually produced according to an international scheme, but have long since gone out of print.

More recently, the United States Hydrographic Office has produced a world series of charts for air navigation, in which a rather different use has been made of the Mercator network. While in the past each sheet has joined perfectly, the scale of each

[15] L. Tonta: Notes on Nautical Cartography, *Hydrogr. Rev.*, Vol. 6, No. 2, 1929, pp. 53-65. This paper was preceded by two others on the subject of polar navigation: A New Type of Polar Chart, *Hydrogr. Rev.*, Vol. 5, No. 2, 1928, pp. 51-60; Notes and Tables on Polar Cartography, *Hydrogr. Rev.*, Vol. 6, No. 1, 1929, pp. 83-110. Tonta suggests the use of a transverse Mercator projection for polar navigation.

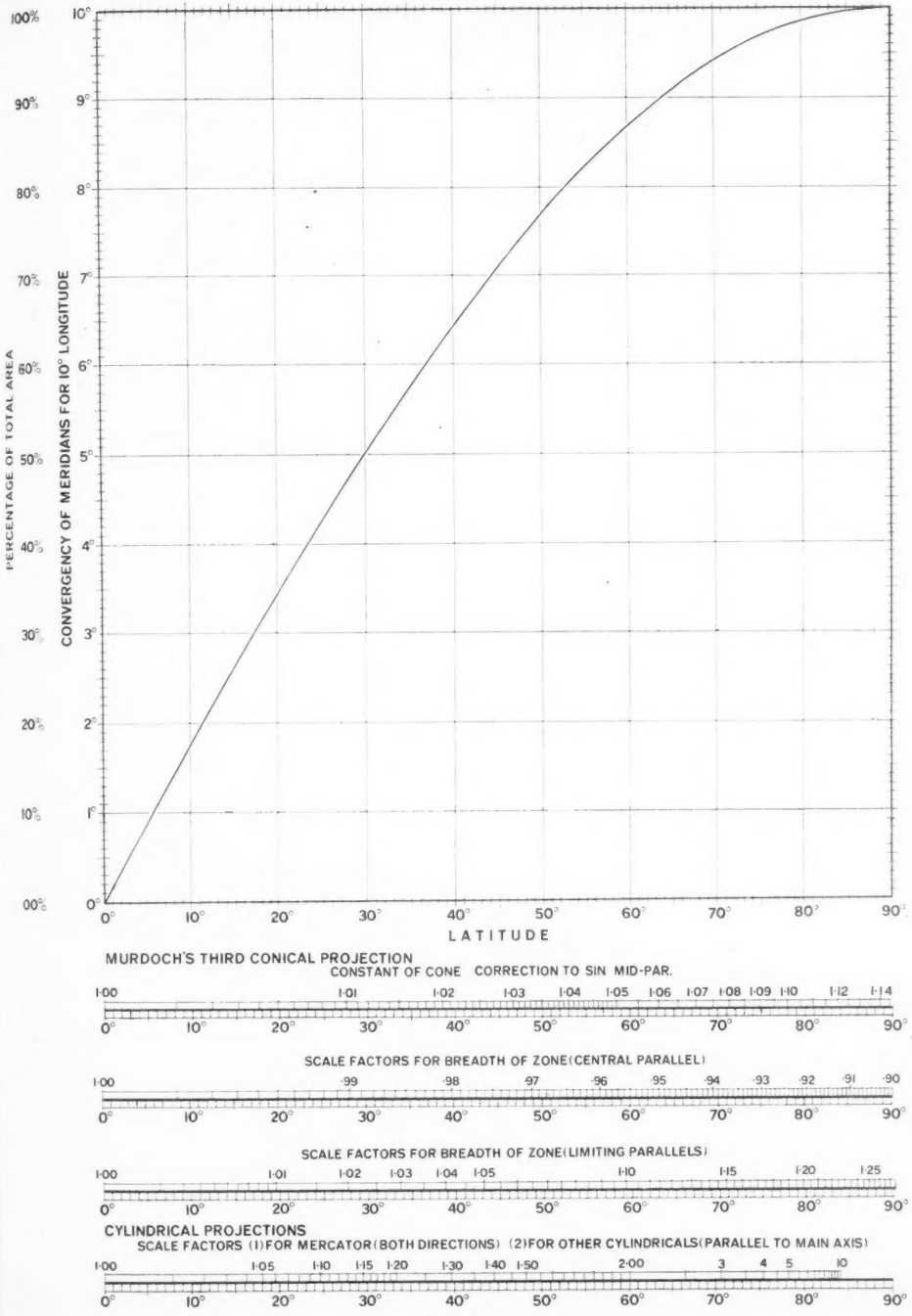

PERCENTAGE OF TOTAL AREA
CONVERGENCY OF MERIDIANS FOR 10° LONGITUDE
LATITUDE
MURDOCH'S THIRD CONICAL PROJECTION
CONSTANT OF CONE CORRECTION TO SIN MID-PAR.
SCALE FACTORS FOR BREADTH OF ZONE (CENTRAL PARALLEL)
SCALE FACTORS FOR BREADTH OF ZONE (LIMITING PARALLELS)
CYLINDRICAL PROJECTIONS
SCALE FACTORS (1) FOR MERCATOR (BOTH DIRECTIONS) (2) FOR OTHER CYLINDRICALS (PARALLEL TO MAIN AXIS)

Fig. 6
Graphical treatment of factors for scale and convergence.

band increasing with latitude, this new series is constructed to a constant scale of 1:2,188,800, or 30 nautical miles to the inch at the central parallel of each band, with a latitudinal range in each case of 15°. The extent of longitude included on each sheet is now variable, and obviously will increase with latitude. Such a system depends on the assumption that similarity of overlap is more important than a perfect fit; and, since Mercator co-ordinates are so easily plotted, there is a good deal to recommend this point of view.

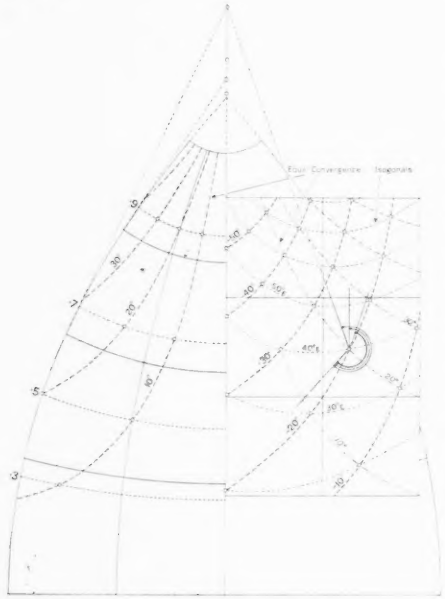


Fig. 7
The derivation of curves of equal convergence (left), and of combined convergence and variation (right).

With the exception of the air edition of the International 1:1,000,000 series on the modified Polyconic projection, the schemes so far devised for a world air map make use of orthomorphic projections of the cylindrical, conical or zenithal types. It remains to ask whether any radical improvements can be effected in the fundamental design of such maps. Two kinds of answer present themselves, and these will be dealt with in such order as to preserve continuity of treatment. The first concerns the possibility of simplifying the measurement of bearings, and leads us to a field of study—the representation of convergence—as yet almost unexplored. Much of the remainder of this paper deals with different aspects of this subject, and the notes which follow will serve as a convenient introduction. The second possibility, the use of an unfamiliar conical projection, will be dealt with later.

The Representation of Convergence

Consider a projection in which every parallel of latitude is standard—that is, equal in length to the corresponding parallel on the reduced earth, and in radius to the radius of the tangent cone. All such parallels are equivalent in every way to the standard parallel of a simple or tangent conic projection. The inclination of the meridians along such a parallel, relative to the central meridian, will depend on the true convergence on the earth[16] at the corresponding latitude and difference of longitude. Points on each parallel representing constant changes of convergence can be plotted by determining the convergence factor for the parallel in question. This factor is similar to the constant of the cone (n), except that the latter applies to the whole range of a projection. It is the ratio between the angle of inclination of two meridians at a given latitude on the earth and their corresponding inclination at the pole. Thus the factor ·5 refers to latitude 30°, and implies that successive meridians 10° apart (say) will be inclined to one another at angles of 5°. Values of this factor for all latitudes on the earth can be taken from the graph (a sine curve) of Fig. 6, where they are expressed as degrees of convergence for each 10° of longitude. Through the points obtained by plotting in

[16] Best visualised as the difference between the bearings included by a great circle which intersects the two meridians at a given latitude.

terms of these factors along selected parallels, curves can now be drawn to represent lines of equal convergence, which on the map means lines of equal inclination of the meridians relative to the central meridian. All this is shown on the left side of Fig. 7, convergence factors being indicated at the edge for certain selected parallels. It is now possible to ignore the ever-changing direction of the meridians, and to measure all bearings on the map from lines parallel to the central axis, applying such correction as is indicated by the curves to find the true bearing on the earth. For navigational purposes we can go still farther, and modify these curves so that they include an allowance for magnetic variation, thereby giving a true magnetic great circle bearing from a map bearing plus (or minus) a single correction. All this is brought out on the right-hand side of the figure, which shows also the method of deriving points on such modified curves from the intersections of isogonals and lines of equal convergence.

So far the limitations of projection have not been considered. In actual fact, no projection exists which can combine the properties assumed in the above description. The only graticule giving any approach to them is that of the ordinary or American polyconic projection. At small scales, however, the curved meridians do not intersect the parallels at right angles; and consequently it is not a tangent to the meridian, but a radius of the parallel, which gives the true angle of inclination to the central axis. There is a further limitation on the use of the polyconic. This method of measurement presupposes that all great circles are to be projected as straight lines. Although the polyconic makes a good showing in this respect within some few hundreds of miles of the central meridian, it shares with all other projections an inability to combine the requirement satisfactorily with accurate representation of convergence. In practice neither the simple polyconic, nor any of the modified members of the class, can be particularly recommended for this method of adaptation. The use of a fresh meridian of origin for each sheet would prove a source of unnecessary difficulty; and in fact the requirements of projection and sheet system at once suggest the use of a conical network.

So far as the representation of convergence is concerned, conical projections differ in certain important respects from members of the polyconic group. The angle between any two meridians is constant for all latitudes and depends on the formula for n, the constant of the cone. Thus if n equals ·7, meridians 10° apart are inclined to one another at angles of 7°. In practice, the value of n is such as to give a true representation of convergence along a parallel near the middle latitude of the sheet. This means that, unlike the example of the polyconic projection, we have to distinguish between map convergence and true convergence on the earth. In the one sense a curve of equal convergence on a conical projection will be a straight line, *i.e.* that meridian which includes a given angle with another meridian chosen as central. In the true sense, a line of equal convergence will be a curve which takes into account the varying convergence at different latitudes on the earth, as in the previous example. To study the relation between these two concepts we may pay some attention to curves of equal error of convergence on a conical projection (Fig. 8*a*). In this figure the value of n (·7) shows that each 10° meridian is inclined to the next at an angle of 7°. To draw lines of equal map convergence at 1° intervals we therefore divide every 10° of longitude into seven equal parts, the meridians so obtained representing 1° of convergence *on the map*. Curves of equal error can be drawn through points where the true convergence is a given number of degrees greater or less than the map convergence, reckoning a chosen meridian as central or 0° convergency. Thus the intersection of longitude 10° (7° map convergence) with the parallel along which this meridian

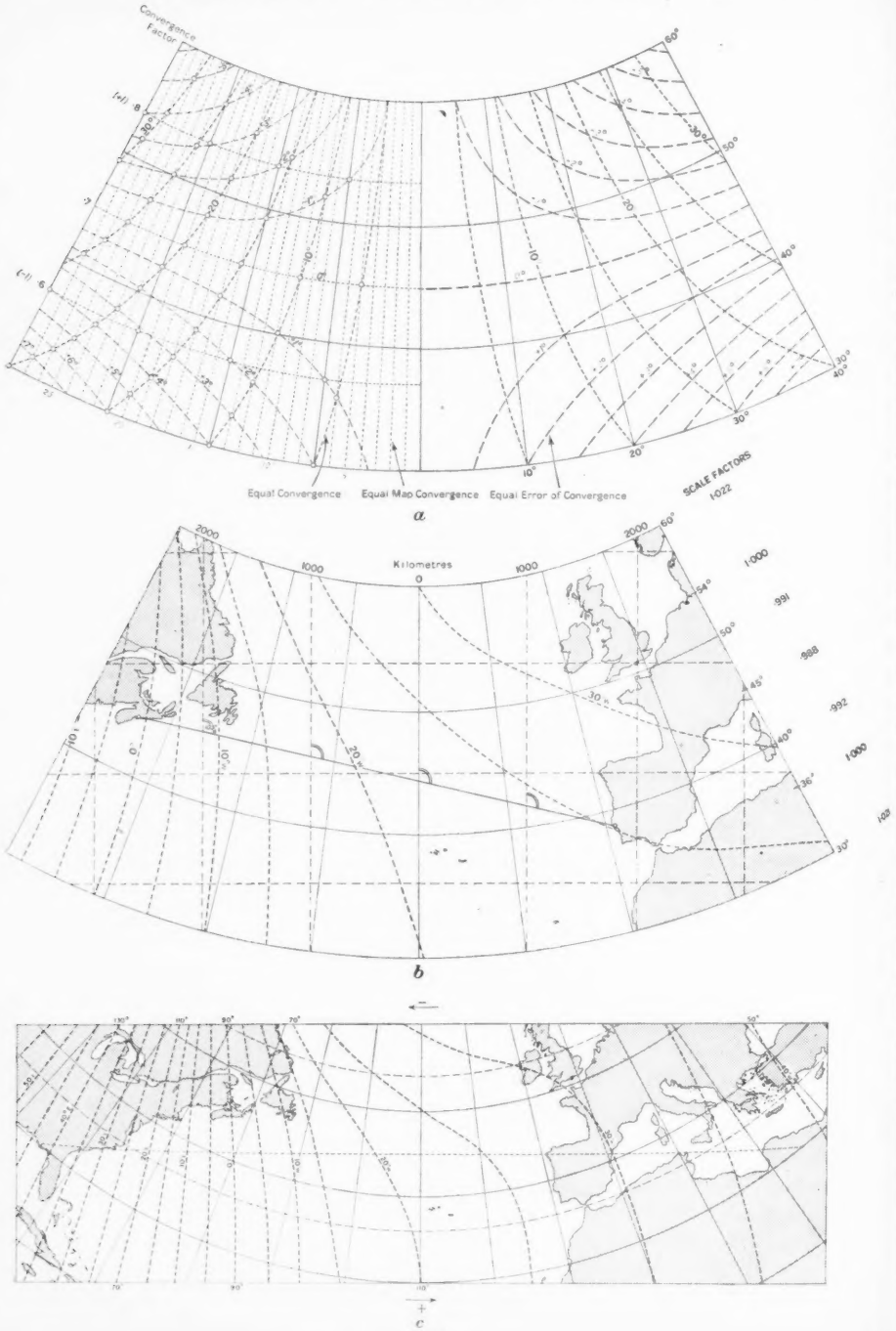


Fig. 8

Combined correction for convergence and variation, and representation of errors of bearing on conical orthomorphic projections.

subtends 8° of convergency on the earth, gives a point on the −1 curve. So far as great circles can be assumed to be straight lines on a conical map, the curves drawn through points arrived at in this way give some idea of the distribution of angular error on the projection.[17]

The lines of equal true convergence on the earth (t.c.) may now be derived from these curves of equal error (e.e.) by noting where the latter cut the curves of equal map convergence (m.c.). Thus the intersection of e.e. −1 with m.c. 9° gives a point on the curve 10° t.c. It will be found that these t.c. curves pass through exactly the same points as do those of the previous example (Fig. 7). In the same way as before they may be combined with isogonals, thus making possible a single correction from chart bearing to magnetic great circle bearing. This has been done in Fig. 8*b*, which is a conical chart of the North Atlantic with curves drawn for the epoch June, 1942. A rectangular system of false " meridians " and " parallels " is included, as well as a sample track along which the true great circle bearing varies from 101° to 128° (magnetic).

At this point it is necessary to interpolate a note about Fig. 8*c*. The writer came to this subject of convergence through the study of polar projections suitable for navigation, and the foregoing outline shows how the approach was made. Some time later he came across Admiral Tonta's pioneer work in the same field, and noted certain differences in treatment. Tonta based his final curves on meridians of equal map convergence, and does not distinguish between these and lines of true convergence. The curves in Fig. 8*c* cover part of the same area as those of Fig. 8*b*, and refer to the epoch June 1942 as before. The differences are due to the fact that they are constructed from lines of equal map convergence rather than from the t.c. curves used in Fig. 8*b*. Apart from the errors introduced by the second method, there is an important practical reason for preferring the first. Only if the t.c. curves are used is it possible to avoid a discontinuity at the junction of two zones of conical projection based on different values of the constant *n*. Studied together, therefore, the three charts of Fig. 8 give a complete summary in graphical form of the practical problems of convergence on this type of map.

It is now possible to see in a general way how curves of equal convergence could be applied to a series of navigational charts. Each sheet would carry false rectangular meridians, and might even carry an approximate rectangular co-ordinate system broadly resembling the kilometric grid used on topographical sheets. Bearings would be measured from the false meridians, a single correction being applied to give a great circle compass bearing, or the mean of two corrections to give a rhumb line compass bearing. This is the main purpose of the system, although the ordinary advantages of a grid—the possibility of using rectangular co-ordinates to determine distance, bearing and position, either on or off the sheet in use—might be made available, though at the cost of a far greater degree of approximation than is allowed on gridded topographical maps. It should be pointed out that the normal graticule would remain on each sheet, and would continue to be used for many purposes. In transferring from one grid to another, for instance, its use would be essential.

The application of the proposed rectangular system to the sheet lines of an overlapping series of conical projections has not yet been worked out in detail. The limits of the " grids " that would be required, together with the choice of sheet system, limiting scale factors and zones of projection, would have to be decided by international agreement, as would all questions of layout and

[17] Although they are ignored in practice, the angular errors inherent in a particular map introduce an additional factor into corrections for true bearing.

style. At the end of this section it will be possible to enumerate some of the main factors bearing on such a choice. To this end it will be helpful to consider the properties of a projection not hitherto used for air maps.

Murdoch's Third Conical Projection

The design of a world series of the kind proposed involves an assessment of the possible combinations of such variables as breadth of zone, scale factors and convergence factors on each of several zones, in order that the most favourable choice can be made. Projections like the conical orthomorphic are not particularly helpful in this respect, since errors of scale vary in an irregular manner on different examples, and are not regularly disposed about a central parallel. This can be seen in Fig. 1, where, for example, a " rolling " fit has not been achieved between the corresponding parallels on adjacent zones. For its practical convenience in this direction and because of its general excellence, it is advisable to glance at a projection not so far used for air maps.

A conical projection first proposed by Murdoch in 1758—the third of a series suggested by him—has been derived quite independently on other occasions, and was resurrected by Young in 1920. In the course of a thorough analysis, Murdoch's Third Projection is described by Young as ". . . . . on the whole the very best of the Conical Class, better for all practical purposes than the absolute Minimum Error. . . ."[18] It is perhaps surprising that to date only one map—the British Council Map of Europe and the Middle East, produced by the Royal Geographical Society—has been drawn on this projection. Since the formulæ and properties are thoroughly discussed by Young and Hinks,[19] it will suffice to note certain properties of particular value. The graticule is of the normal conical type with two standard parallels, and with the meridians truly divided and the total area correctly preserved. Of particular interest is the fact that the scale errors along the extreme parallels are equal and depend *only* on the breadth of the zone. This means that all zones, provided they extend over the same range of latitude, will have the same scale value along the extreme parallels, sheets so constructed having a rolling fit along the boundaries of the zones. From the formulæ for the scale factors the author has constructed two scales giving respectively values along the extreme and central parallels corresponding to any breadth of zone up to 90°. These are shown in Fig. 6. The constant n is given by the sine of the latitude of the mid-parallel multiplied by a factor giving a slight correction. This factor also may be taken from a scale included in Fig. 6, again in terms of the breadth of zone required. It has the effect of moving the parallel of true convergence slightly away from the mid-parallel and towards the nearer pole. This new latitude can be read from the graph, entering it with the new value of the constant n.

Notes on the Design of a World Series

1. Any series giving a complete cover can best be built up from zones of cylindrical and polar zenithal, conical and polar zenithal, or a combination of all three types of projection. Any of these combinations can be made to give a series of sheets that is consistently orthomorphic or equidistant in character.

2. The zones can be so arranged that scale factors are the same along the edges of each, giving a rolling fit between sheets on different projections. This may be particularly useful on small scales, since straight-line courses can be drawn through common points of tangency on two adjacent sheets so as to

[18] A. E. Young: Some Investigations in the Theory of Map Projections (Technical Series No. 1), Royal Geographical Society, 1920, pp. 40-41.

[19] A. R. Hinks (in Map Projections and Sun Compasses)—V. Murdoch's Third Projection. *Geog. Jour.*, Vol. 97, 1941, pp. 358-62.

connect stations plotted on different projections. Even if the entire range is covered by cylindrical and polar zenithal maps, this rolling fit can still be of value. In the orthomorphic version it has been pointed out[20] that Mercator and stereographic maps meet in latitude 36° 52′ 12″, the scale factors on each showing an enlargement of exactly 25 per cent.

3. In all cases these straight-line courses approximate closely to great circles.[21] On the polar orthomorphic chart the difference between the straight line and the arc of a true great circle is of no significance in practice. A full analysis, with formulæ, is given by Tonta.[22] Within reasonable distances of the pole similar arguments apply in the case of the zenithal equidistant map, for which the total scale errors can be made a minimum by introducing a standard parallel. The properties of the conical orthomorphic are well known, while Murdoch's projection is practically equivalent to the absolute minimum-error representation so far as scale is concerned. As with the polar charts, the cylindrical projections differ relatively little near the equator, and the equidistant map is actually superior in its overall approximation to true scale. The difference in length, bearing and departure between great circle and rhumb line is unimportant below latitude 15° or so (see also point 6 below). An analysis of the difference between short lengths of these two courses on conical projections is also available.[23]

4. If the rectangular system of false meridians is to be incorporated in a world series, the choice of a suitable value for the factor n (·6, ·7, etc., according to latitude, or a close approximation thereto) is of some importance, and the mid-latitudes of the conical zones should be chosen with this point in mind. Quite apart from any question of lines of equal map convergence, the value of n will determine the angle between false meridians on sheets adjacent in longitude. If the scale is, say, 1:2M. or smaller, each sheet (in longitude) might carry its own rectangular system, and it would be convenient to arrange sheet lines so that the two central meridians are inclined to one another at a suitable angle. Thus, if each sheet has a longitudinal range of 20° and the value of n is ·6, the two sets of false meridians will be inclined at an angle of 12°.

5. The junction between conical and polar projections need present no great difficulty, since the central meridians of the former would be inclined to the meridian of origin of the polar system of curves at the angles indicated by successive longitude values; for on the polar maps the constant n has become unity, and meridians are inclined at their true difference of longitude. This holds good only if the whole polar area is covered in one or two sheets and lines of equal map convergence are used as a basis for the curves. In many cases it will probably be better to proceed as follows. Considering each column of sheets based on a central meridian, construct the appropriate sector of the polar map as a rectangular sheet extending at least to the pole. This will ensure good overlaps for trans-polar routes and will make possible an uniform treatment of the curves giving correction to true bearing.

6. Similarly, a junction with a cylindrical zone would produce no difficulty near the equator; for the curves would be shown in the usual way on the cylindrical map and would be drawn in respect of a "central meridian" as before. The effect of the correction would still be to give an approximation to the magnetic great circle bearing.

[20] L. Tonta, *op. cit.*, Vol. 6, No. 1, 1929, pp. 88-89.

[21] This statement is intended to cover ranges of latitude up to some 15° from the central parallel.

[22] L. Tonta, *op. cit.*, Vol. 6, No. 1, 1929, pp. 90-94.

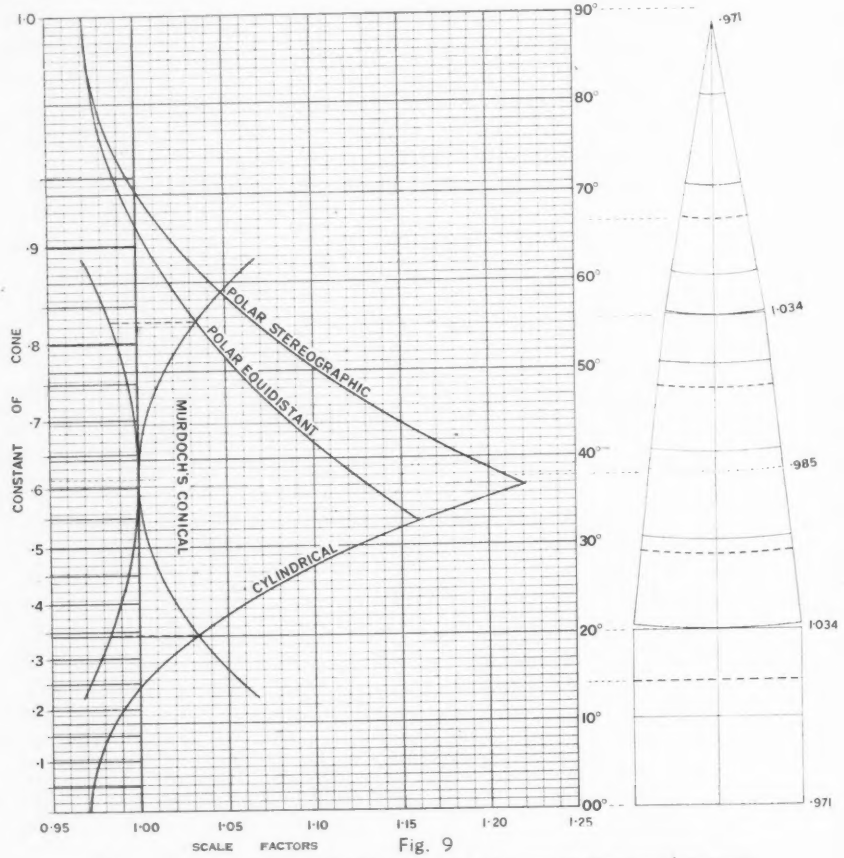
[23] L. Tonta, *op. cit.*, Vol. 6, No. 2, 1929, pp. 60-62. With reference to this question of loxodromic distance, the present writer has constructed a scale giving rhumb-line distances in statute miles from arguments of bearing (between 15° and 74°) and difference of latitude.

7. This discussion brings out the importance of basing the correction curves on lines of *true* convergence, so that continuity is maintained throughout the various zones.

8. In order to retain a desirable overlap between sheets, it might be convenient to use the graticule limits as the true boundary of each sheet, at the same time enclosing the whole area in an outer border defined by the rectangular system. The distinction between the two could be indicated by completing the resulting overlaps in outline only, as on another well-known series.

9. The choice of standard parallels, and the position of the junction between zones, are both of less importance than the equalisation of the scale factors.

10. Cylindrical and polar zenithal maps can be constructed with standard parallels or with true scale at pole and equator. If standard parallels are used on orthomorphic maps of these types, the meridian scale is reduced in the same ratio as the parallel scale in each case; but if the equidistant projections are used, the meridian scale of the cylindrical map will remain true, while that of the polar map will be reduced. In Murdoch's projection the meridian scale will remain true along the entire length of the conical zone.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CONSTANT OF CONE
POLAR STEREOGRAPHIC
POLAR EQUIDISTANT
MURDOCH'S CONICAL
CYLINDRICAL
0·95
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1·20
1·25
SCALE FACTORS
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70°
60°
50°
40°
30°
20°
10°
00°
·971
1·034
·985
1·034
·971

Fig. 9

Approximate graphical method for selection of zones to give complete cover.

A rough preliminary estimate of the possibilities for any proposed arrangement of projections and zones can best be made by preparing a diagram like that of Fig. 9. It consists of a number of graphs of scale factors, each covering a wide range of latitude. Polar orthomorphic and equidistant curves are shown (parallel scale for latter) and a parallel scale suitable for all cylindrical projections. The diagram in its present form is made possible by the practical convenience of the Murdoch network; and graphs have been included for both central and limiting scale factors, and for a wide range of breadths of the conical zone. If these various scales are drawn on transparent paper, they can be moved about until any desired combination of conditions is satisfied. Thus a selected value for n may be combined with various breadths of zone or with a variety of ranges in scale factors; and so on.

The layout of sheets shown in the figure is chosen as a simple example of the possibilities. More complicated schemes could of course be treated in exactly the same way.

3. GREAT CIRCLE ROUTE CHARTS

With certain modifications, we may expect the long-distance route chart of the immediate future to follow the general lines of the remarkable series produced in 1932 by Louis Kahn, the projection being an oblique Mercator and the scale 1 : 10,000,000.[24] In nearly every case such route charts will presumably be drawn on an oblique cylindrical projection, in which the cylinder of reference is assumed either to be tangent to the sphere along the great circle route or to intersect it along small circles (straight lines) parallel to and equidistant from the great circle on the map. In the simpler case the scale will be uniformly true along the great circle, and uniform also, but enlarged as the secant of the angular distance (θ) from the centre, along all parallel small circles. The degree of enlargement is the same for all cylindrical projections, and its range is shown in Fig. 6. Along great circles (straight lines) at right angles to the route the scale may be true (simple cylindrical), reduced as cos θ (equal-area), or enlarged as sec θ (orthomorphic or oblique Mercator).

The second type of case includes the oblique cylindrical stereographic map shown in Fig. 2, where two small circles of true scale are used, the central great circle between them being reduced to less than true scale. The breadth of zone may be chosen to limit the maximum scale error along the edges to the same value (though of opposite sign) as that along the central route.[25]

Strip maps of this kind, constructed along a chosen great circle, would require only a limited range on each side of the route. For such ranges there is comparatively little difference between the simple cylindrical, the cylindrical orthomorphic, or any of an infinite number of compromise solutions between these standard types. All are at their best near the great circle of tangency.

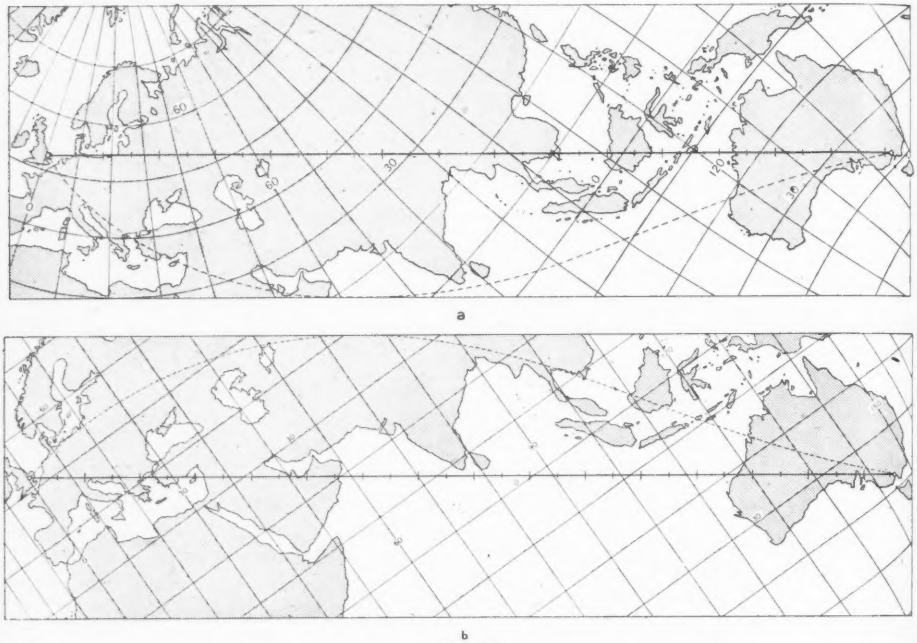
A route chart on the oblique Mercator projection for the great circle between London and Melbourne is shown in Fig. 10*a*. The chart extends to an angular distance of 25° on each side of the route. These oblique cylindrical maps differ from various other available types (conical, polyconic, etc.) in that they preserve an equally high standard of representation for *any* selected great circle, this being accomplished at the expense of the meridians and parallels, which (at very small

[24] Apparently Kahn's system was first outlined in a note presented at a meeting of the Academy of Sciences, Paris, on Feb. 20th, 1928, and recorded in Publication No. 8. See also L. Kahn: Sur Une Extension de la Projection de Mercator: Les Nouvelles Cartes Aériennes. Académie de Marine, *Communications et Mémoires*, Tome 8, 1929.

[25] For a good example of this type of map in simple cylindrical projection, see Sir C. Arden-Close (in Map Projections and Sun Compasses)—I. An Oblique Rectangular Cylindrical Projection, *Geog. Jour.*, Vol. 97, 1941, pp. 349-50.

scales) become complex curves. It is here that the advantages of curves giving the correction from map bearing to true bearing is most clearly demonstrated. The method as described above for conical projections can be applied to cylindrical strip charts in almost exactly the same way as before. It may be an advantage to give the correction from map bearing to true bearing in such a way as to use the direction of the route as zero map bearing. As is seen in Fig. 8*c*, this implies using two sets of values—one for the direction of the forward route, and one for a journey in the opposite direction. This method of numbering the curves is illustrated on the edges of the figure, and its relation to the normal system is at once apparent. On these oblique cylindrical projections the curves are constructed as before from lines of equal magnetic variation and lines of equal convergency on the earth. In addition, it will be necessary to take into account the angle between the meridian of the starting point and the direction of zero chart bearing, as here they are no longer identical.

What are the possible alternatives to the use of oblique cylindrical projections for long range strip charts? Fig. 8*c* gives a general idea of the practical limits of the conical orthomorphic for this purpose. Provided the standard parallels are well chosen and the route is predominantly in an E.-W. direction, it is possible to approximate a great circle by a straight line over a distance of several thousand miles. In the example the great circle (slightly curved) is shown as a pecked line, while the parallels shown in the same way are the standards. Even in an E.-W. direction, however, the change of latitude would soon become excessive, although errors of convergence arising from



a

b

Fig 10

(*a*) Great-circle route London-Melbourne in oblique Mercator projection.
(*b*) Rhumb-line route London-Melbourne on Poole's Modified Mercator projection.
Scale: 1:130,000,000.

this cause are allowed for when the curves giving true bearing are constructed in the correct manner. It will be remembered that those in the figure do not include this allowance, since they are based on map convergence rather than on the convergence of true meridians.

Turning to routes in a predominantly N.-S. direction, it might be thought that, since curved meridians are now no handicap, the ordinary polyconic projection, with its very favourable showing along a central meridian, would come into the picture. Although it might be suitable for the purpose, it is probable that a *transverse* case of the cylindrical orthomorphic or the corresponding simple cylindrical (Cassini's projection) would still be preferred.[26]

Finally, we come to a route chart of a different kind—one constructed for a loxodrome or rhumb-line course rather than for a great circle course. The rhumb line on this projection differs from the straight line on a Mercator chart in that the scale along it is constant, although the projection remains approximately orthomorphic in the neighbourhood of the central route. These two properties—true scale and orthomorphism—are combined near the centre by drawing the straight parallels at their true distance apart, while at the same time varying the distance between straight meridians in such a way as to retain true scale at the mid-latitude between each pair of intersections of the meridians with the rhumb-line route. The projection was designed in 1935[27] to cover the very suitable case of the route from England to Australia, which at that time wandered between the direct loxodromic and great circle courses. This is the case shown in Fig. 10*b*, where it is drawn to the same scale as the oblique Mercator chart of the corresponding great circle route. Loxodromic and great circle courses are indicated on both charts, the difference in distance being given by the difference between the lengths of the respective axes, each of which is graduated at intervals of 300 nautical miles.

4. SPECIAL AIDS IN PRE-FLIGHT DETERMINATIONS

Whatever improvements in navigational technique are foreshadowed in the immediate future, it is fairly safe to assume that the basic pre-flight determination of the elements of long courses will still be needed, and will continue to follow established practice. How far does the foregoing discussion help in suggesting improvements to the normal procedure? To attempt an answer to this question it is necessary to return to the study of convergence, and to follow out still further its representation on different map projections.

The curves of equal convergence which we have derived from the polyconic projection really refer to the varying inclination of the meridians, *considered along any particular parallel.* Strictly speaking, they do not give the correct answer when we require to know the convergency betwen the ends of *any* straight line or approximate great circle. Although these curves have been derived independently for other projections, and although they may be used on charts where measurements *are* made between any two points, they can do no more than approximate to the unique conditions of a particular route. To study an *accurate* series of such curves we must make use of a zenithal projection specially constructed for a "centre" or point of tangency chosen as one end of an infinite number of great circle routes whose convergence we wish to portray. Fig. 11*a* shows part of a stereographic projection centred on London. Great circles through the centre are straight lines, and cut all meridians, including the central meridian, at the true bearing. Such a chart

[26] Similarly, oblique polyconic projections offer no particular advantages over cylindrical types.

[27] H. Poole: A Map Projection for the England-Australia Air Route, *Geog. Jour.*, Vol. 86, 1935, pp. 446-48.

can therefore be of value in the study of true convergence.

Fig. 3 of the writer's earlier paper[28] may be used as a starting point. There it was shown that the convergency between the centre A and a second point B is given graphically by the angle α included between a tangent to the meridian of B and the central meridian, this angle being measured at the point from which the parallel of B is described. From this relationship it was possible to establish a simple graphical method of obtaining lines of equal bearing radiating from the centre. This line of thought is continued in Fig. 11*a*. If lines were laid off at a constant angle α (shown in the example as 30°) from the centres of each of the parallels of the chart, the series of intersections with the respective parallels would trace out a curve of equal true convergence, and this curve would be accurate in respect of all great circles passing through London. In the figure such curves are drawn at intervals of 10°. Their relationship with curves of equal bearing (short pecks) passing through London is also shown. If straight lines are drawn to radiate from the centre at intervals of bearing of 10°, their cuts with the true convergence curves will give points on these curves of equal bearing. The reasons for this can be worked out from the figure, where it can be seen that any of the three series of lines can be derived from the other two.

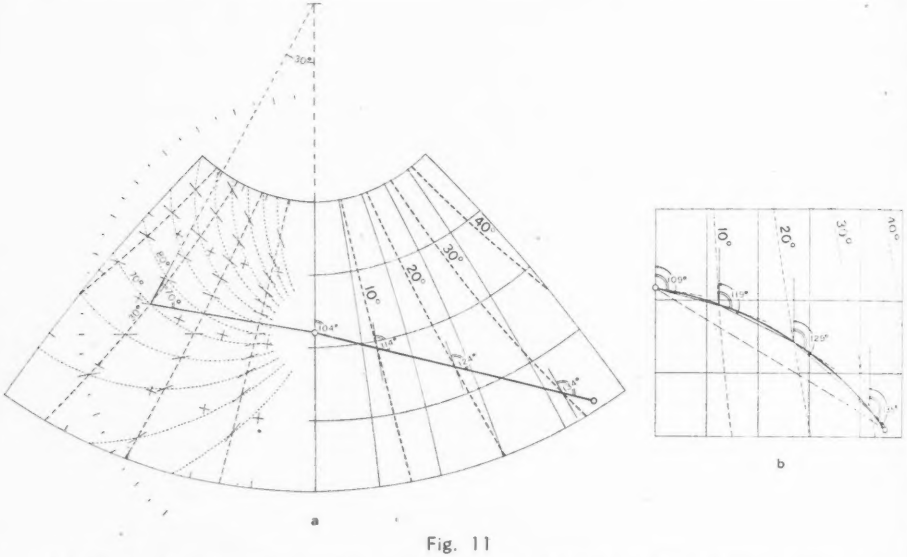


Fig. 11

(*a*) Stereographic projection centred on London, and showing relation between curves of equal convergence from centre (coarse pecks) and of equal reverse bearing (fine pecks); also (on right) elements of route London-Basra.
(*b*) Mercator projection of same route, to show derivation of chord courses from curves of equal convergence.

What are the practical advantages of curves of equal convergence? Apart from their uses in aiding the conversion from rectangular chart bearing to true compass bearing, these curves help to simplify the preliminary determination of the elements of great circle courses. The method of working is illustrated on the right-hand side of Fig. 11*a*, showing the route London to

[28] Dilloway, *op. cit.*, *Jour. Roy. Aer. Soc.*, 1942.

Basra on the stereographic, and Fig. 11*b*, showing the same route on Mercator's projection. Instead of choosing the successive legs of the rhumb-line chord courses in an arbitrary manner, we select them at equal intervals of convergence along the great circle. All that is then necessary is to apply one half the convergence interval to the first true great circle bearing to give the first chord course, changing this by the full amount of the convergence interval at the end of the first chord to give a second chord course; and so on until we reach the end of the last complete chord, when one-half the convergence interval, plus one-half only of the estimated convergence to the end of the route, is applied to give the final bearing. The method of working for this example is shown in the two figures. The conclusion at once emerges that all the elements of great circle routes passing through a particular station can be obtained at once from an oblique stereographic chart without recourse to a Mercator base chart. If the related zenithal equidistant projection is used instead—Fig. 12 shows an example for the hemisphere centred on London—the measurement of distances along these great circles is reduced to its simplest form, while none of the essential properties are affected.

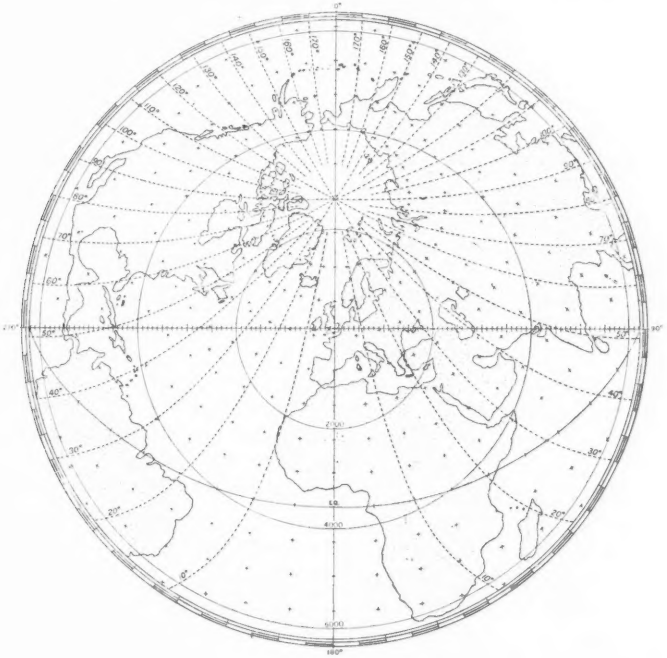


Fig. 12

Zenithal equidistant hemisphere centred on London showing curves of equal convergence from centre and distances in statute miles. True bearings from centre can be read on outer circle.

From Fig. 12, with its facilities for reading initial bearings, convergency, and distances in statute miles to all other points (to say nothing of curves of equal reverse bearing and the elements of chord courses) it is clear that a series of such charts, constructed for various important centres and to a fairly large scale, would be of value in planning long-distance routes. Whether the curves on such charts allow for convergence only,

as in Figs. 11 and 12, or whether they combine an allowance for convergence and magnetic variation, makes no difference whatever to the method of use. The bearings shown in Fig. 11 require a separate correction for magnetic variation.

The procedure to be followed on conical projections equipped with false rectangular meridians and curves giving true magnetic bearings is exactly the same as that described in the preceding paragraph, and illustrated in Fig. 11. A long great circle route would be broken up into a number of shorter lengths, each to be flown on a constant magnetic bearing. Changes of course would be made at points determined by the curves, the rule being that no leg should be of such a length that the difference between the curve values at the ends exceeds a small number of degrees. This proviso is necessary in view of the approximations involved —notably that of using a mean magnetic bearing. In effect, the convergence curves are seen to be a medium through which the properties of conical and Mercator charts are to some extent reduced to a common form.

By statement and by implication we have now arrived at a fairly complete picture of the effects of applying corrections for convergence on map projections of various types. Which of the two kinds of correction —for convergence only or for combined convergence and variation—will be preferred in a particular case, will depend entirely on whether magnetic or non-magnetic directional indicators are to be used.

CONCLUSION

The new methods and ideas put forward in this paper, in the course of a survey of the problems of world air charts, are roughly of two kinds. First, designs are produced for new devices to aid the study and protraction of world routes in the office. These are the geared stereographic hemispheres of Figs. 3, 4 and 5, and the auxiliary device of Fig. 12. Second, new methods are proposed bearing on the design of navigational charts for the entire globe. These are comprised in a fairly thorough general treatment of suitable projections and sheet layout; and of what has now been termed " grid navigation." Throughout it has been assumed that the new pressure of a single world environment will come to prevail over current motivations, and that all such problems will eventually be dealt with by a single world authority. For this reason the object has been to attain a degree of refinement sufficient only to allow an assessment of possibilities and a preliminary layout of designs. To this end the discussion has been deliberately simplified; firstly, by employing the spherical assumption in all descriptive matter; and secondly, by omitting all reference to mathematical analysis and formulæ where these are available in standard literature.

Much of the discussion of navigational charts has centred round a method of overcoming the difficulties of converging meridians. The basis of such a method was thoroughly worked out some years ago by Admiral Tonta, Director of the International Hydrographic Bureau, and is now beginning to arouse serious interest. Quite recently the present writer had occasion to construct a polar chart embodying the same principle —presumably the first chart of the kind to be prepared; and it was partly in this way that he came to attempt a more general interpretation of the basic idea. A similar interest has been aroused in the United States, and has now been focused in a paper by Prof. Samuel Herrick just received.[29] In this paper the subject of " Grid Navigation " is dealt with from the standpoint of Admiral Tonta—that is, curves of correction to true bearing are based on lines of equal map convergence taken from conical charts. The need for an additional correction to enable the great circle to be approximated by a series of

[29] Samuel Herrick: Grid Navigation, *Geog. Rev.*, Vol. 34, 1944, pp. 436-56.

short chords is not specifically brought out, and the treatment of a straight-line track is somewhat simplified. On the use of strip charts Prof. Herrick refers to a proposal by Mr. Douglas Matthews for a projection constructed along a great circle route, with straight meridians inclined to the great circle at the true bearings and with parallels obtained by dividing the meridians equally. An asymmetrical approximation of this kind would offer no advantages over an oblique cylindrical chart, and the present writer can see little future in such a method, although at first sight it has often seemed to him to be a tempting solution.

What are the simple advantages of " grid navigation "? As Prof. Herrick points out, it allows the use of a drafting machine, eliminates a good deal of work on conical projections, and requires little alteration to existing charts. Other advantages are brought out earlier in this paper, notably the ease with which a magnetic great circle course can be followed by applying to the initial "rectangular" bearing the mean of a pair of curve values. As to the extent to which, for navigational purposes, the grid could replace a graticule of meridians and parallels, the writer feels that further experiment is necessary, particularly with the various operations of celestial and position-line navigation.

What of the relation of world flying routes to the distribution of human settlement on the face of the globe? From a spate of claims and counter-claims the importance of at least two strategic centres appears to be demonstrated. If the world's land areas are mapped on a polar projection, as in Fig. 3, regions of dominating importance are seen to be grouped around the north pole. Allowing for the exaggerations of commercial publicity, and despite fog and other seasonal difficulties, the polar region seems destined for a measure of air-route development.[30] In theory, at any rate, the problems of polar navigation do not present any unusual difficulties, while the use of false rectangular meridians on polar charts offers the simplest example of the advantages of the " grid " method—not separately treated here for the polar case because of its general applicability.

The properties of Fig. 4, centred on London, are exactly similar to those of the polar map. Figs. 4 and 12 help to confirm the fact that London, though not precisely the " centre of gravity " of the world's land hemisphere, is as close to it as makes no difference.[31] This fact, and its position astride the routes linking the Old World with the New, may help to account for a growing conception of London as a potential exchange centre of cultures, with air communication as one of the vital links. But the picture depends in part on the existence of a world air organisation; and in this matter the state of opinion in the Americas suggests the possible formation, as a temporary expedient, of an international air authority for the non-American world. This Old World area includes most of the world routes, and even before the war accounted for well over half the total of air-miles flown. In relation to it, London would exchange a central for a peripheral position; but its world position would remain the more important. Against this last idea, on the other hand, may be set the well-established fact—not yet of great moment—that geographic centres of population, in common with other indices of civilisation, are trending slowly eastward in the Old World and westward in the New—both in the direction of the Pacific!

[30] A general treatment of certain aspects of the subject, including a rather optimistic tabulation of savings in great circle distance, is given by Elmer Plischke: Trans-Arctic Aviation, *Econ. Geog.*, Vol. 19, 1943, pp. 283-91.

[31] The true centre, established according to the conventions of " centrography," is located near Nantes, in France. A good general treatment of this and various other centres (all much farther removed from London) is given by Erwin Raisz: Our Lopsided Earth, *Jour. of Geog.*, Vol. 43, 1944, pp. 81-89.

Of necessity this paper has ignored certain aspects of mapping for world aviation. Nothing has been said about the design of the map picture, and no mention is made of suitable scales,[32] or of the number of series required. All such matters would fall conveniently within the terms of reference of a newly constituted International Commission. During the last few years sufficient experience and sufficient basic material have been accumulated in this field to bring an agreed decision within easy reach. All that needs to be underlined here is that this whole subject possesses both an extreme topical interest at the present time and a great and growing importance for the future.

[32] An international series on the scale of 1 : 2,000,000 should be well suited to the new range of world flying. It is at these scales that the "grid" method is seen to best advantage.

CIVIL AVIATION DISCUSSION

A MEETING of the Royal Aeronautical Society was held in the lecture hall of the Institution of Mechanical Engineers, Storey's Gate, St. James's Park, Westminster, London, S.W.1, on Tuesday, January 23rd, 1945. In the chair: Dr. H. Roxbee Cox, Fellow of the Society.

The purpose of the meeting was to discuss and to vote on a motion concerning the development of civil aviation.

The CHAIRMAN: He announced with regret that Sir Roy Fedden (President of the Society), who had intended to preside, had been involved in a motor accident and was unable to attend the meeting. Whilst unfortunately two of his companions appeared to have been seriously hurt, Sir Roy was not so seriously hurt and there was every reason to hope that he would not be away for very long.

Coming to the subject for discussion at the meeting, the Chairman recalled that the Society had held an all-day discussion in November, 1944, on a variety of matters of importance in civil aviation, under the very able chairmanship of Lord Brabazon, and on the whole the Council felt that it was not unsuccessful. Nevertheless, it had come in for some criticism, to the effect that it was too long—it had lasted about seven hours—and that the variety of subjects discussed was really too great. As a result, a number of people felt that they had heard a great many diverse opinions, but that no one subject had been adequately thrashed out.

Consequently, the Council of the Society had decided to experiment along rather different lines and to arrange a number of short debates, each on a single subject, so that the pros and cons of each subject could be thoroughly ventilated and the trend of informed opinion defined. The present meeting was the occasion of the first debate, and the second would be held on March 13th, 1945. If the Council felt that the experiment was a success, it would be repeated.

The motion for debate was:—

> "That in the opinion of this meeting it is reasonable that organisations experienced in transport services—for example, shipping and railways—should take part in the development of civil aviation."

The following gentlemen had accepted invitations to speak for and against the motion:—

In favour:

Mr. Arthur Gouge, Past-President of the Society.

Major K. M. Beaumont, a recognised authority on air transport and air law matters.

Mr. Farey Jones, of North-Eastern Airways Ltd.

Against:

Mr. D. McIntyre, Managing Director, Scottish Aviation Ltd.

Mr. T. Rice, District Manager in the United Kingdom for Pan-American Airways.

Group-Captain G. W. Williamson, of David Brown Ltd.

The Chairman emphasised that the object of the debate was to bring out the points in favour of and against a particular motion of considerable general interest. The speakers would be arguing a case, and were not necessarily stating their personal views.

He added that the meeting was not solely composed of members of the Society, and that even if it were, it would only represent

a small proportion of the membership. Consequently the vote at the end of the debate would only reflect the opinion of the meeting, and must not be regarded as representing the view of the Royal Aeronautical Society.

He regretted to say that Mr. Gouge had been unable to attend the meeting, and he called upon the Secretary to read Mr. Gouge's remarks.

Mr. A. GOUGE (Past-President): To be able to run successfully any transport service, it is important that certain fundamental requirements are fulfilled, or that the necessary knowledge to attain this requirement can rapidly be acquired.

In the great expansion of aerial transport which can be foreseen in the near future, it would seem advisable to encourage any organisation, which is equipped, or even partly equipped, with the fundamental requirements to participate in air transport.

Consider for a moment what these requirements are, and see if the railway and shipping companies are in a position to help this country to develop rapidly its aerial transport. There was no need for him to stress at this meeting how important is the question of speed of development.

Apart from the financial requirements which are necessary and which he was taking for granted the railway and shipping companies have, the other main requirements seem to be:—

(1) It is necessary to have some knowledge of the means used for transport.
(2) It is necessary to know much about the goods you are going to transport.
(3) It is also necessary to have experience of ground facilities which go with and are an essential part of the operation of any transport system.

So far as (1) is concerned, it cannot be said that either the railway or shipping companies have a great knowledge of operating aircraft though the railways operated aircraft before the war and are doing so now—and, as far as he knew, doing it very well. Certain of the shipping companies were interested in air transport, particularly those overseas.

Any lack of experience in this direction, however, should soon be overcome, and an immense number of young men have been trained during this war to both operate and maintain aircraft. It should therefore be easy to recruit staff with the knowledge required.

It is also obvious that in the higher ranks of the Royal Air Force, particularly Transport Command, there must be well-qualified officers who would be able to undertake management responsibilities.

Regarding (2), there is no question whatever that both the railway and shipping companies in the course of their present business have gained all the knowledge required about how to handle passengers and goods. They also know what is in some ways more important, the mistakes to avoid.

Regarding (3), both the railway and shipping companies have the necessary knowledge and experience how to deal with passengers and goods once they arrive at their destination. He would say this is particularly so of the shipping companies. These companies have branches all over the world and are therefore particularly well situated to start almost at once handling any traffic which may arise.

He hoped from these few remarks he had shown that generally both railway and shipping companies are in a position to assist in aerial transport. As pointed out, they have the finance and most of the technical requirements, and he would have no hesitation in saying that, given the opportunity, both railway and shipping companies could help very successfully in British air transport.

Personally he could see no reason why it should ever be assumed that it was not a good thing for the British railway and shipping companies to participate in the development of British air transport. If companies

such as these are not allowed to participate, then it would exclude everybody and British air transport would be run as a monopoly by some State-controlled body.

It appeared to him to be very essential in the development of a new business or industry that encouragement be given to any companies or concerns who wish to participate, always providing they are qualified to do so, both financially and technically.

He would not like to be read into his last words that he thought the development of a business like aerial transport should not be controlled or governed. This he considered to be very necessary, particularly from the technical aspect. Also he personally felt that a certain amount of controlled competition is essential if an efficient industry is to be developed.

It can, of course, easily be stated that they would get competition from overseas and that they would be wasting their effort to compete amongst themselves. However, he thought this was far from the truth. Any business, in his opinion, is improved in its early development by a certain amount of competition, and while there is no question whatever that they would get competition from overseas, the problems of other countries are not British problems. This is a point which he thought was not appreciated sufficiently in this country.

Before the war they had a very large shipping fleet whose business it was to carry goods and passengers to the four quarters of the globe. This business is going to be relieved of a certain amount of its trade by air transport, and it should therefore be their business to see that British air transport is developed to take as much as possible of the trade which the shipping companies are bound to lose.

The type of aircraft which has to be developed to run the air service for this purpose is not necessarily the same type as developed to run airlines internally in another country. They must do their own development for these particular routes, and in his opinion a certain amount of controlled competition will help the development.

In his opinion there were no better people to run these particular lines than the shipping companies themselves. The same remarks in general apply to the railway companies, except that their traffic is very much nearer home.

Mr. D. McINTYRE (Managing Director, Scottish Aviation Ltd.): The Chairman had pointed out to the meeting that this is a debate in which the speakers state their case, not necessarily their convictions.

It so happens that his case coincides exactly with his convictions, formed on twenty years of practical experience in aviation, and especially on the experience of the last four years, during which he had, with the assistance of a specialist technical staff, been engaged in the practical operation of a modern international airport which is to-day handling a far greater volume of long-distance trans-Atlantic air traffic than all the traffic of pre-war Croydon.

He thought it should be clearly appreciated at the outset that, contrary to all of the very powerful propaganda of surface interests, air transport is an entirely new and revolutionary form of transport—entirely different in technique, method and mentality from any older form of surface transport.

In the course of only forty years it has been developed logically and efficiently by men with aviation minds. It was their skill, enterprise, courage and devotion which overcame not only the mechanical problems, but lack of funds, public apathy and opposition, bringing air transport to the point at which it stands to-day.

It would be deplorable, having reached this stage, if a meeting of the Royal Aeronautical Society considered that aviation men were now incapable of running their own business and had to fall back on the assistance of the elder surface transporters. In certain countries it might even be construed as a sign of decadence.

Until a nation has used a wide network of internal airlines at costs within the means of a large proportion of its population, and thus familiarised itself with air transport, it can have but little aviation mentality and few constructive views to offer.

During that temporary period of partial ignorance, public opinion is very open to be misled by those who consult only selfish interest, or by those who have only recently given thought to the subject and whose outlook is therefore superficial and unlikely to be sound.

As they would imagine, he did not plead for a square deal for the railways, except in their own sphere. His case was that of a square deal for the whole British public, which will receive immense and unimagined benefits from a timely and seemly enlargement of commercial air transport.

His own experience has proved to him that there is absolutely nothing that surface transport industries can contribute to that process apart from money and political pull. Aviation will be much better without both of these, unless it is the right type of money and the right type of political pull, directed solely towards the enlargement and development of air transport.

The plea which is normally made by railway and shipping companies is that their existing ticket offices, agencies and other facilities would be of advantage to air services. The hard fact is that air transport has already built up for itself a technique and psychology of passenger and freight handling, and ticket systems, on entirely new and modern lines, which are so highly efficient that it would be a most retrograde step for air transport to revert to the old-fashioned methods, psychology and facilities of the surface transport industries.

"Co-ordination of Transport" has become a stock phrase of the railway and shipping companies, and much is made of the point that partnership in the railway air plan is open to all comers. It has recently been their boast that nine shipping companies have accepted that offer.

Another stock phrase in their propaganda is "Wasteful Competition," but it is all unsatisfactorily vague in meaning, and at best is only one side of the picture; the other side having some sinister implications.

Co-ordination of transport is a simple function of Government whose powers in this respect cannot be usurped by commercial undertakings. And does not all this talk about "Co-ordination" and "Wasteful Competition" sound remarkably like a formula for a commercial monopoly?

Clearly, it will be time enough to talk of co-ordination of air transport when the airlines have brought one class air fares to the travelling public below that of third-class railway fares—a stage which they would reach within five years if aviation companies who are in aviation for aviation's sake are allowed to apply their virile determination to this aim.

He need not ask them to imagine just how far British railways would have been developed if their growth and encouragement had been in the hands of stage coach operators and canal companies. And, for that matter, how far would British merchant shipping have been developed if its enterprise and energy had been restricted to that of a branch of the Admiralty?

But he *would* ask them to consider the debate that evening in relation to the position in America, where the enterprise of the individual, and reasonable competition, is fully encouraged on the public's behalf by the Government, and where the control of one form of transport by another is definitely forbidden by one of the Republic's fundamental laws—a law which has probably contributed more than any other to the vast development of that country, which, having started from scratch in the 17th century, now numbers some 140 million inhabitants, as compared with Canada's eleven millions and Australia's eight millions.

The test there, which is applied to all new transport undertakings, is the clear practical test of public necessity and convenience—a test which if applicable in this country would have obviated such a debate as this ever taking place.

In America no one transport industry is allowed to control another, and the benefits of this have been proved time and time again, and passed on to millions upon millions of ordinary American citizens.

Had he time, he could give them endless human examples of the effect which this law has had in developing the widespread transport arrangements which have been the basis of American progress and their high standard of living.

Both America and Canada have made their policy abundantly clear by legislating for the strict divorcement of surface transport from any connection with air transport. Can conditions and fundamental principles be so entirely different in the two hemispheres that they could believe for one minute that 150 million enlightened people can be wrong, and dare they blind themselves to the proof of their principles?

He thought he could illustrate the American view more clearly on this subject by a short quotation from the U.S. Government's case when this law was applied to a shipping company which had developed an overseas airline and was forced by law to divest itself of all interest in that airline. Here is the U.S. Government's case:—

"The legislative policy thus developed had a background of experience. New modes of transportation had rarely been pioneered and developed by those engaged in older forms of transportation. The older transportation agencies had generally resisted the new, and had entered the new field only after its commercial possibilities had been demonstrated and the new transportation had come to be regarded as a competitive threat to the old. Congress, in adopting the restrictive provisions of Section 408 of the Civil Aeronautics Act, evidently intended that air carriers should be free to act independently of conflicting interests and feared that in the absence of strict public control *these air carriers might become the economic captives* of financial interests whose primary concern would be the protection of their investments in other forms of transportation."

It must be clear to every unbiased mind that where there is competition between the various forms of transport, each finds its own natural level, all the higher because it has had to strive to reach that level. Each develops on natural lines, and the mass of the population reaps the benefit in lower costs and extended services. Where an older form of transport controls a new there must be the tendency to provide a safeguard for the small minority of the public who are shareholders, to the detriment of the large majority of the population who are not. But the majority of the population is entitled to all of the benefits of the new instrument—and is fully entitled to be protected against the reduction of these benefits and against the delays which would be introduced if older forms of transport obtained a grip over the new.

Finally, he would like to emphasise that at this moment when they must make up their minds to be an airfaring nation in an airfaring age, they should be particularly careful to step forwards and not backwards. He was convinced that they would step backwards and never recover if the encouragement of British air transport is merged with the dogmas, financial obligations and almost overwhelming political influence of the surface transport industries. They could not have air transport operated to the old-fashioned standards of railway trains, or aircrews being paid off at the end of each flight, as is the practice in shipping. He was equally certain that they would take a step forward if they ensured that the development of air transport is placed in the hands of

those who have brought it thus far—who have proved their faith and singleness of purpose in the development of air transport—and who can therefore be trusted to foster the commercial air transport services of this country without regard to any interest but that of public necessity and convenience.

He did not think that railway or shipping companies should take a part in air transport.

Major K. M. BEAUMONT: In the public interest, which is what should always *primarily* be studied, it is essential that purveyors of air transport should be equipped with enterprise, expert knowledge and experience of carriage of traffic.

In the early days of flying, as in the early days of motoring, the main objective was to get the vehicle from one point to another without breakdown or mishap. Only forty years or so ago it was quite a hazardous adventure for a motorist to undertake a journey from London to Oxford. Even when the dangers and difficulties of tube-ignition had been superseded by electricity, he had to tackle broken valves and valve springs, faulty plugs, sticking commutators and innumerable tyre bursts, complicated by security bolts—if nothing worse.

In the same way, a pilot who made a journey only from London to Paris about twenty-five years ago was quite a hero, likewise his passengers, in aircraft which could only just be hoicked over the boundaries of muddy aerodromes before the single engine overheated and stalled.

In those days air transport was difficult and dangerous—a matter for experts in piloting, navigation, maintenance, etc., since aircraft were tricky, engines unreliable and aids to navigation non-existent. Nowadays, with concrete runways, automatic pilots, radio, radar, beams, blind-landing facilities, multi-engines that seldom fail, greatly increased range and speed, and a constant supply of expert flying, navigational and maintenance personnel available from Transport Command and the R.A.F., the movement of the vehicle from one point to another, over long stages, is one of the problems of air transport *most* easy of solution.

Particularly in *international* air transport there are much more knotty problems which are common to *all* forms of international carriage—for instance, the difficulties inseparable from transit between and through foreign countries (including Customs, immigration, quarantine, police regulations, etc.), the maintenance of an up-to-date fleet of vehicles for the various services required, capable of competing successfully with international rivals, the provision for the various types of customer (users of mails, passengers and owners of goods) of the class of transport which each requires at the cost which each is able and willing to pay, and generally the observance of the maxim that "The customer is always right"—without the carrier ruining himself. All these problems, and many others, are common to international carriage generally and outweigh greatly in importance and number the problems peculiar to air transport.

In all such matters international shipping and railway undertakings have acquired a mass of knowledge and experience which constitutes a good foundation for exploiting air transport; and in the case of international *shipping* companies they have foreign bases and experienced agencies ready to handle traffic where they require to operate and where they have probably been operating in a manner to which passengers and shippers are accustomed.

Naturally they would have to acquire the specialised knowledge indispensable for air operations—for instance, the intricacies of the Paris, Warsaw and other international Conventions applicable to the air, including perhaps a new Convention arising out of the Chicago Conference. These would be in addition to those of the Brussels and Berne Conventions, which have long constituted the bibles respectively of the international

marine and rail carriers. But this knowledge is readily available on application to those who have for many years made a special study of the subject—for instance, himself.

Somewhat similar arguments are applicable to the participation of rail and road organisations in *internal* air transport. Indeed, where international complications do not have to be faced, the differences between the air and older forms of transport are fewer. Consequently it should be easier for the surface carrier to adapt himself to transport by means of the more modern vehicle.

It is sometimes objected that if marine, rail and road carriers undertake air operations, their tendency will be to suppress the air side in favour of their original vehicles. He suggested that no carrier who is enlightened enough to balance his fleet by the incorporation of the most modern vehicles would be so foolish as to act thus, especially if confronted by international competition, with which he has had to contend for many years. If he does not provide his customers in all categories with the form and class of transport they respectively require, at or below the cost at which they can obtain it from his rivals, he will lose his business and go broke.

If the marine, rail or road carrier studies and learns the special respects in which air transport differs from other forms of carriage, and acquires the technical personnel necessary to handle those aspects which differ from those of which he has great experience, he saw no reason why he should *not only* make a success of this, but also perhaps import into it methods learned from long transport experience which may improve upon those of concerns which have concentrated solely upon the air. In any event, he could not see that *users* of transport will suffer in consequence of surface carriers being allowed to enter into competition. On the contrary, the travelling public and other taxpayers should benefit from enlargement of the field of potential air carriers. And, to repeat his original axiom, it is the interests of the public which should primarily be studied.

The CHAIRMAN: The next speaker, Mr. Rice, wished it to be understood that he would express views formed on the basis of American experience and applicable in America. He did not wish his remarks to be regarded as in any way indicative of what was appropriate for British civil aviation. The Society was grateful to him for speaking; it would be interesting to consider the applicability of the points he made to our own particular problems.

Mr. TOLBERT A. RICE: He would like to open his part in this debate by emphasising the fact that his remarks to follow do not necessarily represent the views of the Management of Pan-American Airways. Also he wanted to state that he was arguing against the motion as it applies to the United States. For rather obvious reasons it was not his place to indicate to what extent he believed his arguments applied to any other country.

Many years ago the Congress of the United States passed an Act which, in effect, made it unlawful for a railroad company or other common carrier to control any common carrier by water, with which the railroad or other carrier might compete for traffic. A Congressional Committee which sponsored this Act made the following statement:—

> "The proper function of a railroad corporation is to operate trains on its tracks, not to occupy the waters with ships in *mock* competition with itself, which in reality would operate to the extinction of all *genuine* competition."

Now that statement was made in 1912, but does it not make just as much good sound sense to-day as it did thirty-three years ago?

In the course of its regulation of the various forms of inter-state and foreign transportation, the Congress of the United States has consistently sought to prevent companies engaged in one form of transporta-

tion from having controlling interests in companies engaged in another. Basically, it has determined that the different forms of transportation should be developed as independent industries.

This policy rests upon a variety of considerations, among which the more important are: the fear that the older forms of transportation—as a result of their established position and financial power—might dominate and restrict the newer; the belief that the newer forms of transportation can be developed more effectively by companies not controlled by carriers engaged in a *competing* form of transportation; and the desire to restrict interlocking relationships between competitive interests in public service generally.

As is known, the American steamship companies are now strenuously endeavouring to have this policy rescinded. Now of course these companies contend that the operation of airlines by them over their steamship routes would not be detrimental to the development of civil aviation. On the contrary, they state that their present ground organisations would be of great benefit to the development of civil aviation, and that the formation of integral air-sea systems would be a great step forward in international travel. The plea is also heard that as foreign shipping lines are making plans to operate aircraft in conjunction with their ships, the American shipping companies will be in a hopeless competitive position unless they also are allowed to utilise aircraft. Then one hears that the utilisation of aircraft by shipping companies is merely a *modernisation step*—much the same as the change-over from sail to steam.

Let these arguments be examined. It is all very well to say that joint operation of ships and aircraft along the same routes would not be detrimental to the full development of civil aviation—but let them put themselves in the position of the directors of a company which controls both forms of transport in a certain area. The company has a very large investment in shipping and a very much smaller investment in its auxiliary airline. As business men and as servants of the shareholders, is it not an obvious duty to increase the return on the large investment wherever possible, at the expense of the return on the smaller one? In other words, the air investment would be little more than an *economic tool* with which to protect the very much larger shipping investment. *Surely civil aviation deserves a better fate than that*!

Next is the argument of the steamship companies that their present ticket offices, ground staffs, etc., would be very beneficial to the development of civil aviation. In actuality, the two forms of transportation are so essentially and fundamentally different that this present ground organisation would be of little use in the development of a ground organisation competent to handle air traffic. Air operation requires specialised personnel such as dispatchers, meteorologists, aircraft and engine mechanics, and even the sales and traffic-handling personnel must utilise an approach and technique entirely different to that of their counterparts in the much slower land and sea transport companies. *Aviation is essentially dynamic.* Its progress in the next decade should be little short of spectacular, considering recent developments in aircraft design, metals, fuels and methods of propulsion. Surely it is not fair to the travelling public to tie this fast-moving industry to the established organisation of surface transport. Even granting—which he did not—that the existing ground offices of surface transport would be of benefit to the development of civil aviation, *without any doubt it is far simpler to establish an office at the end of an airline than it is to establish an airline at the end of an office*!

Now as to the integrated transportation system they had heard so much about. The paramount aim of all engaged in transportation should be to give the public the best possible service at the lowest possible

fares and rates. He freely admitted that this aim will be enhanced by an integration of the various modes of transportation; however, he certainly did not admit that it is necessary to put all of the various forms of transport under one management to obtain this integration. It is *quite* feasible to integrate transportation through traffic conferences, operator associations, agency agreements, and in numerous other ways. For years it has been the practice of international airlines to offer the sale of air-sea tickets. For example, by arrangement with all of the shipping lines operating on the North Atlantic it has been possible for a traveller to enter an airline office and purchase a round-trip ticket to Europe—one crossing by sea and the other by air. The cash discount for a round-trip ticket is given, although one crossing is by sea. Naturally the steamship companies and travel agencies also sell these tickets. This is just *one* example of the type of integration that *can and will* be accomplished in the peaceful years ahead, without recourse to joint ownership.

As he had previously indicated, the American steamship companies are now claiming that they will be in a hopeless competitive position if foreign shipping companies are permitted to operate aircraft. For the sake of argument, let them be taken at their word and *assume* that a shipping company without aircraft cannot compete with a company operating aircraft. The only conclusion to be reached from this assumption is that if they are to have the same number of shipping companies after the war as before—and the war has certainly proved that they did not have too many before—then *all* shipping companies must be permitted to operate airlines. Anyone with the slightest notion of what the future air traffic might be and the number of aircraft needed for its carriage must realise that such a proposal is completely absurd.

He thought the modernisation argument—that is, the comparison between the change from ship to plane, and the change from sail to steam—deserves the briefest treatment of all. It is one thing to change the method of propulsion and *quite another* to change the entire medium and vehicle. He submitted that in the realm of transport, the aeroplane is no more related to the steamship than the V2 rocket is related to the tank in the realm of weapons.

Is it not true that ground transport interests have a *public responsibility* to improve and amplify their existing facilities in line with technological and other developments—as such facilities will certainly continue to be *vital* to the economic and social progress of *any* country? Their fears of competition from the air appeared to him exaggerated, as the airlines should primarily create their own traffic. In testimony before the United States Civil Aeronautics Board, it was recently estimated that 65 per cent. of the future trans-Atlantic air passenger traffic would be newly created, whereas only 35 per cent. would be diverted from surface transport. Does it not seem logical to assume that the strong stimulus aviation will give to all forms of travel and foreign trade will gain an amount of business for the shipping companies in excess of this lost 35 per cent.? There will always be people who desire to travel by sea. He thought that he could say, without jeopardising his job, that there is nothing he enjoyed more than an ocean voyage on a comfortable ship.

That is the case against the American surface transport companies participating in civil aviation, as it appeared to him. Naturally he had assumed that their airlines would continue to be privately owned, no matter who operated them.

Mr. Farey Jones: He congratulated the Royal Aeronautical Society on having the courage to arrange a debate in this form before the aviation fraternity. One of the leading aviation journals of the world, in its issue last week, rather cast doubt on the advisability of discussing, under the ægis of this Society, a matter which it refers to as

political, and implied that it would be far wiser for the Society to discuss purely technical matters, such as blind landings, and so on. He held the view, and he thought it should be expressed here, that the personnel concerned with the running of air transport are as much a technique as the finest piece of mechanism that they could have on the dashboard of an aircraft, or anything else connected with airline operation.

Frankly, having listened to the very remarkable speech by Mr. McIntyre and knowing the great work that his company has done so very efficiently, and putting his and Mr. Rice's remarks side by side with the doubts cast by the journal to which he had referred, he could not help feeling very much as Alice in Wonderland must have felt. Here they were in 1945; and a great leader of Scottish aviation, and a doughty champion they had had to import from the other side of the water to oppose this motion, try to prove that there is no room for railway and shipping personnel to participate in air transport. Surely, if he accepted that, he must accept that they were a nation of ostriches.

After all, what does air transport seek to do? Are those who are connected, directly or indirectly, with air transport seeking to claim that only airmen can take part in the development of air transport? That is a complete fallacy, and it is a view which, however sincerely held, will in the long run do harm to the community, for if air transport is to be of any use at all, it has got to serve the man-in-the-street; and the man-in-the-street will only use air transport and aeroplanes when the air transport or aeroplanes provided will take him anywhere he wants to go with the maximum of safety and the minimum of delay.

Because air transport, so far as we in Britain are concerned, is not a matter of covering the British Isles only, but has to be regarded as a matter for the British Commonwealth, it is inevitable, sooner or later, that any single journey which the average air passenger will take will involve, at some part of the distance between his home and his destination, the use of a bus, a train or a ship. They could not divorce those three from air transport. In his opinion air transport, if it aims at anything at all, aims at the carriage of the maximum number of people and the maximum amount of cargo to the maximum number of places in the shortest possible time and with the minimum of inconvenience. They could not achieve such an object without some form of rail-sea-air co-ordination. Therefore it is desirable that persons experienced in transport services be allowed to come in.

One of the main lessons which this war had taught them was that the Navy, Army and Air Force are inter-dependent. Each arm can deliver a blow to the enemy in its own particular way; but it has been proved that when all three Services have been welded together into a co-operative whole, the force of the blow is more than trebled. That applies equally to shipping, railways and air transport. The railways deliver passengers and freight to the ports and docks, the shipping companies take them over the oceans to other ports and docks, where they are again picked up by the railways. Railways and shipping have immense and complicated systems covering the whole of the Empire. They have staffs who have devoted the whole of their lives to transport. Add to this enormous organisation the benefits of civil aviation, with its fast long-distance passenger and freight traffic, and you have a triumvirate which will take the world in its stride. All three are working for the same object; why not work together?

Can any of them say that because a man is a railwayman or a shipper he must be excluded from air transport counsels? They were not discussing whether or not the Southern Railway or any other particular railway company or shipping company shall come into air transport as a particular railway or shipping company. They would give some British organisation the powers of a

British aeronautics authority. Then they could say that if a shipping or railway company wants to come into the air business it must form an air company; it may use some part of its shipping or rail business, but it must not come in purely as a shipping or rail line because there must be some co-ordination.

He supposed that at least one-third of the wealth of the British Commonwealth had been destroyed during the last five years. They were faced with the task of rehabilitation, not only of the British Empire, but also of certain nations in Europe who have fought side by side with them. When the war ends they would be faced with the task of providing the day-to-day bread and butter for the people, and unless air transport is allowed to play a vital part in that work they might just as well pack up shop now. Air transport must bring to Britain and to British people everywhere something of the standard of life which their friends in America enjoy. Having just come back from there, he thought the one approach to the problem should be to invite the key personnel in the railway and shipping industries to co-operate.

When the war is over they had to rebuild their trade with South America and other foreign countries. In 1934 he did an aerial survey of West Africa and the South Atlantic, and, in common with his friends at Lloyds and the Baltic Exchange, tried to start a British air service to South America with the object of increasing their trade, or even recovering it. Could they imagine that they could exclude the shipping companies from that?

Group Captain G. W. WILLIAMSON (Fellow): Human nature being what it is, it is possible to prophesy that certain commercial unions might be as ill-starred as the lion lying down with the lamb. What would they think of a canal company taking over the running of the railway lines? There may be gas companies which also operate electrical utilities; and they had heard of railways which would undertake the running of road haulage companies.

In considering whether an organisation which may be moribund should undertake the running of another far more up-to-date, they must retain a sense of proportion. There would be no objection to the extension of a railway line or shipping route by means of air transport, wherever the proportion of capital as between airline and surface transport was small. This would be comparable to a railway 900 miles long operating a shipping service across the Channel.

But if it is proposed that the capital allocated to the airline should exceed 25 per cent. of the total, the union will be an uneasy one unless certain safeguards are adopted well in advance of the organisation being built up.

They had a first-rate example of such a union in the transfer of capital by Hitler from the railways to the roads—an organisation so disastrous that it might well prove to have lost him the war. However, in the absence of a Hitler in this country they were not likely to see a transfer of the major proportion of the capital from the older to the newer form of transport.

In an extremely important paper read before this Society, Dr. Roxbee Cox set out certain essential features of any air transport organisation. The first was safety in flight; no airline will long remain a success unless safety first invariably takes pride of place, as with any independent airline. Would this always be so if the airline were controlled by other than disinterested directors?

They have had examples of expediency overruling the policy of safety first in commercial air transport during the war. Following on recent accidents, it was said that military expediency had resulted in more admirals being lost in the air than at sea. This might be coincidence; but aircraft losses under military control could quite easily be compared statistically with peace-time losses in Imperial Airways or British Airways on similar flights.

In the post-war period they faced a greater risk than either political or military expediency—the risk that financial considerations should be allowed to come before safety first. A hastily organised aircraft operating concern, pulled together during the war, was found to have a high accident rate. Immediately its well-qualified directors, long accustomed to aircraft operation, became aware of this, they instituted an investigation which resulted in a greatly increased expenditure on inspection and the supervision of maintenance work. The board changed, the new directors possessing little or no aircraft experience; approximately £50,000 a year might have been saved by getting rid of several senior supervising engineers, a highly qualified chief inspector, and a number of other maintenance men; and the result was a reversion to a higher accident rate which in the end cost the State more than the money saved.

No debate, whatever its results, will stave off the operation of airlines by other utilities; but a discussion such as this may at least draw attention to the extreme shortage of qualified controlling personnel for commercial air transport companies; and full consideration of the difficulties of operating this new type of transport may possibly result in a lower accident rate for those airlines operated by shipping companies or the railways.

It is not necessary for any of them to wait until statistics show that a higher proportion of passengers than pilots are being killed before guarding against this very danger. It is possible to prophesy whether or not an airline will be safe merely from an examination of the proportion of total cost expended on maintenance. If that proportion falls below a certain minimum, a minimum quite easily determined from past operation costs, the accident rate will rise.

Even the Royal Air Force, controlled by pilots rather than business men, has not always been above reproach in its engineering organisation. Immediately after the last war the proportion of maintenance men was drastically reduced, and it was not until a remarkable series of accidents drew attention to the low standard of maintenance that an inspection organisation was built up which must literally have saved thousands of lives. But the service showed exactly the same disinclination to take advantage of commercial practice and aircraft engineering organisation that one might expect from organisations such as railways and shipping companies, who may have become hidebound by old-fashioned belief.

For some years it will hardly be worth while making any money.

But within five or ten years, financial considerations will presumably again take their rightful place; and expert advice and assistance will then be required by companies without previous experience of aircraft operation. One of the serious features of this proposal that these older forms of transport should take over control of the air is the suggestion that they could do so without any alteration in their boards of directors. This is indeed false economy and would undoubtedly prove disastrous.

Looking on the bright side, however, let them suppose that the new organisation is willing to learn from the experience of the independent airline operators. If so, there will be no tendency to save money on those parts of the organisation which are not seen by passengers. Safety first must be the policy; and the inspection and maintenance personnel must not fall, in proportionate cost, in quality and in quantity, below those of the independent airlines.

Ships and railways run very closely to their schedules; passengers by airlines controlled by the people who make and keep those schedules may find themselves travelling by aircraft which always leave prompt to time, but at the cost of a higher accident rate; this risk must be foreseen and guarded against.

In addition to a reasonably proportionate expenditure on inspection and maintenance,

any aircraft concern without previous operating experience should ensure that there is a sufficient expenditure on equipment and on the training of all types of pilots and engineers.

They were already faced with the prospect that airlines would certainly be run, perhaps on the grand scale, by surface transport companies. To sum these rambling remarks, the accident rate might be reduced to a figure comparable with that attained by the older companies merely by consideration of the following suggestions:—

i. The aircraft side must not be starved of capital merely because more money is made on operating ground transport.

ii. The proportion of directors on the joint board should at least be in proportion to the capital allocation; indeed, in view of the greater difficulties likely to be experienced with air transport, the new organisation should have more than its exact share on the board.

iii. The allocation of capital and operating costs to engineering, maintenance and inspection should not fall below the proportion found right by older companies.

iv. The chief engineer on the airline side should be responsible to the board; in no circumstances should he be responsible to a traffic superintendent, a chief pilot or, worst of all, a chief engineer who has been concerned all his life only with the operation of surface transport.

Satisfactory operation of an airline will depend upon communications of a standard rather above those applicable to surface transport.

Mr. GANDAR DOWER (Allied Airways (Gandar Dower) Ltd.): Although he had been asked to oppose the motion, he was speaking in favour of it by reason of a statement he had written in *The Times* recently.

Being thus forced to support the motion that shipping and railways should take a part in civil aviation, he added that certainly they should not take a part which constituted anything approaching a monopoly.

Examining their claims, he said that in the field of international operation it would appear that shipping companies could establish a more natural claim than could the railways. He suggested that, provided an airline had not been established on a route, a shipping company which had operated regular passenger or freight services between two points should be considered for air operation on that route provided no other airline company could offer a better service.

If shipping companies felt aggrieved that air development had got in front of them, it should be remembered that they had displayed little or no interest during the years **1933-38**, when they could have developed routes before that marvellous thing called the " chosen instrument " was born. Their lack of interest was evidenced by the fact that there was no mention of them in the Cadman report. However, he excluded from that criticism Messrs. S. Instone & Co., and paid tribute to the late Sir Samuel Instone as a true pioneer.

As an example of lack of interest on the part of the shipping and railway companies, Mr. Gandar Dower recalled that when the Scandinavian route was opened, between Newcastle, Stavanger and Oslo, and a five-years' concession obtained, the shipping companies were approached, but none had seemed interested. The attitude of the L. & N.E. Railway Company was the same. He could not see that the railway companies had as strong a case to operate internationally as had the shipping companies, except on routes where, *before the outbreak of war*, they could claim to have had large interests in shipping companies.

Would the railway companies come into civil aviation nowadays with completely clean hands? It should be remembered that between **1933** and **1938** they had held back the development of civil aviation by denying independent companies facilities to sell air

travel tickets at recognised travel agencies, under the threat of withdrawing the rail ticket sales. Mr. Farey Jones had asked that that should be forgotten; but one found that to be a little difficult. Why should those independent companies have been unable to sell their tickets in the recognised fashion? They were already handicapped by lack of aerodromes and meteorological facilities, and by poor wireless; one could refer to many ghosts of forgotten airlines. The difficulty was not removed until 1938, and it was removed because Parliamentary pressure was brought to bear on the railway companies, which had then to appear before the air transport licensing authorities in order to get their own licences. They had then recanted.

Why did the railway companies always slow up the development of other forms of transport? He was told, for instance, that if they had not purchased the canals there would have been greater development. Again, why were the bookings for road transport services made at small shops in side streets? Because of the ban.

He urged that the pre-war independent companies had the right to resume, and that the railways and shipping companies must go to the licensing authorities, internationally and nationally, to stake their claims.

Group-Captain S. A. DISMORE: Speaking from an experience of a quarter of a century in air transport, he said he would welcome anybody who could help to develop it. Air transport would become the biggest thing in the world and it could not afford to lose anybody. If he should have any association with any air transport concern after the war, he would welcome with both hands those with experience of railways and shipping; he would hire them, just as they were suggesting in some quarters that they should take in people having experience in the air.

But he opposed the motion before the meeting because there was more in it than that. Having worked very hard in air transport, he had determined that during his few remaining years in it he would never again be at the mercy of the people who controlled the finance. Air transport could hire shipping people and railwaymen, and they could work together as a united team. But it would be fundamentally wrong for any one business or industry or branch of transport to attempt to control another branch of transport. They could work together as a happy partnership, integrate their traffic, make booking arrangements, and so on. But air transport must never be under the control of any other system of transport or under the control of financiers.

Twenty-one years ago the very much maligned "chosen instrument"—Imperial Airways—had asked the investing public for £500,000, and it was subscribed very quickly by the clergymen's widows, retired Army officers and others who usually invested in small amounts. They had come forward because they had had faith and believed that British Empire air communications would do good in the world. With the exception of his old friend, Sir Samuel Instone, he did not think any shipping company had subscribed a penny piece, unless they had done so through nominees. Even so, there were no large individual amounts. Again, when Sir Alan Cobham was trying to get an opposition show going on the route to the Cape, he had gone to them cap-in-hand. A shipping baron had given him a good lunch and then, bending down from his 6-ft. 7-in. of height, had said "My dear boy, you will never carry our mail in your aeroplanes."

Leave air transport to the air people; they had faith in it, they had given their lives to it, and they would welcome all the help that could be obtained from railwaymen, steamship men and road transport operators. But do not attempt to control it through those concerned with other interests.

Mr. THEODORE INSTONE: He supported the motion whole-heartedly; indeed, he sug-

gested that it was not strong enough. He would have preferred it to have been worded to the effect that in the opinion of the meeting it was desirable that persons experienced in the transport services of shipping and railways should by right take a prominent and active part in the development of civil aviation. The transport services of this country generally had been run so well by the transport people that he had no hesitation in urging that the shipping and railway companies should definitely be allowed, and indeed should have the right, to run air services in conjunction with their other services.

Some speakers seemed to think that the railway and shipping companies had no right to interfere or to dare to want to run air transport. But in fact the railway companies had run air services for some years. He was a shipping man and he had had the privilege of being a pioneer, with Sir Frederick Handley-Page, in running British air services.

There were two, three, four or five very important committees in this country which had been considering and taking evidence on what should be done with air transport; he had the honour of being a member of the committee comprising the Associated Chambers of Commerce, the London Chamber of Commerce and the Federation of British Industries, of which committee the chairman was Sir Oliver Simmonds, M.P. Those various committees had taken exhaustive evidence and had come to the irresistible conclusion that not only should those interests which had been running air services prior to the war be allowed to continue, but also that the railway companies and the shipping companies should be allowed and should have a right to run air services in conjunction with their present general transport services.

Many of the speakers against the resolution had really supported monopolies in this country, or had wished to support monopolies, but had not the pluck to say so. The country did not want monopolies or combines or cartels; the public were against them; they were not good for the country. They wanted healthy competition by those best fitted by experience to run air transport services.

REVIEWS

Radio for Aeroplanes. D. Hay Surgeomer, A.F.R.Ae.S. Longmans, Green and Co., 1944. 3s. 6d. net.

The advance of radio in the last five years has been tremendous and secret. There is little doubt that when all the information is released of the progress which has been made that the ordinary man will be astonished and, when the results of this progress can be adopted for his every day use, gratified beyond measure.

There is opening out a new industry, a new field of endeavour, for many. This little book, the fifth in the Air Training series, is a simple explanation of the fundamental principles of transmission and reception. It calls for no previous knowledge of electricity.

The author has written a number of these elementary introductions and is well qualified to do so. The first two chapters deal with the fundamental properties of electricity and magnetism, and the next two with alternating currents. Chapter V is concerned with the Electromagnetic waves, the necessary introduction to the remaining six chapters on transmission, reception and use of electromagnetic waves. Mr. Surgeomer has almost succeeded in getting a quart of radio information into a pint pot. He has certainly packed more information about electricity in these 120 pages than is to be found in books of considerably larger size, and has done his packing with a skill which makes the book readable and worth while to the many who are now looking forward to radio as a career, either in aviation or in any other sphere.

A Bibliography of Aviation Medicine Supplement. P. M. Hoff, E. C. Hoff and J. F. Fulton. Committee of Aviation Medicine, Division of Medical Sciences, National Research Council, Washington, D.C., 1944. $2.50.

The astonishing growth of aviation in all its branches during the war period is emphasised by the necessity of publishing this Supplement to the Bibliography of Aviation Medicine which was first published two years ago. Over a thousand entries a year have been added, the Supplement containing 2,214 new entries, carrying the total number of references to Aviation Medicine to close on 8,000.

The divisions and sub-divisions naturally follow those of the main Bibliography and it is a tribute to the original volume to note those headings which have the statement beneath them, " No new entries," indicating how thoroughly the original survey was made.

For all those concerned with the behaviour of the human element in aviation the Bibliography and its Supplement are invaluable sources of reference, classified both by author and subject. They are, indeed, model bibliographical productions, and one hopes that the example set will be followed in time in every branch of aviation.

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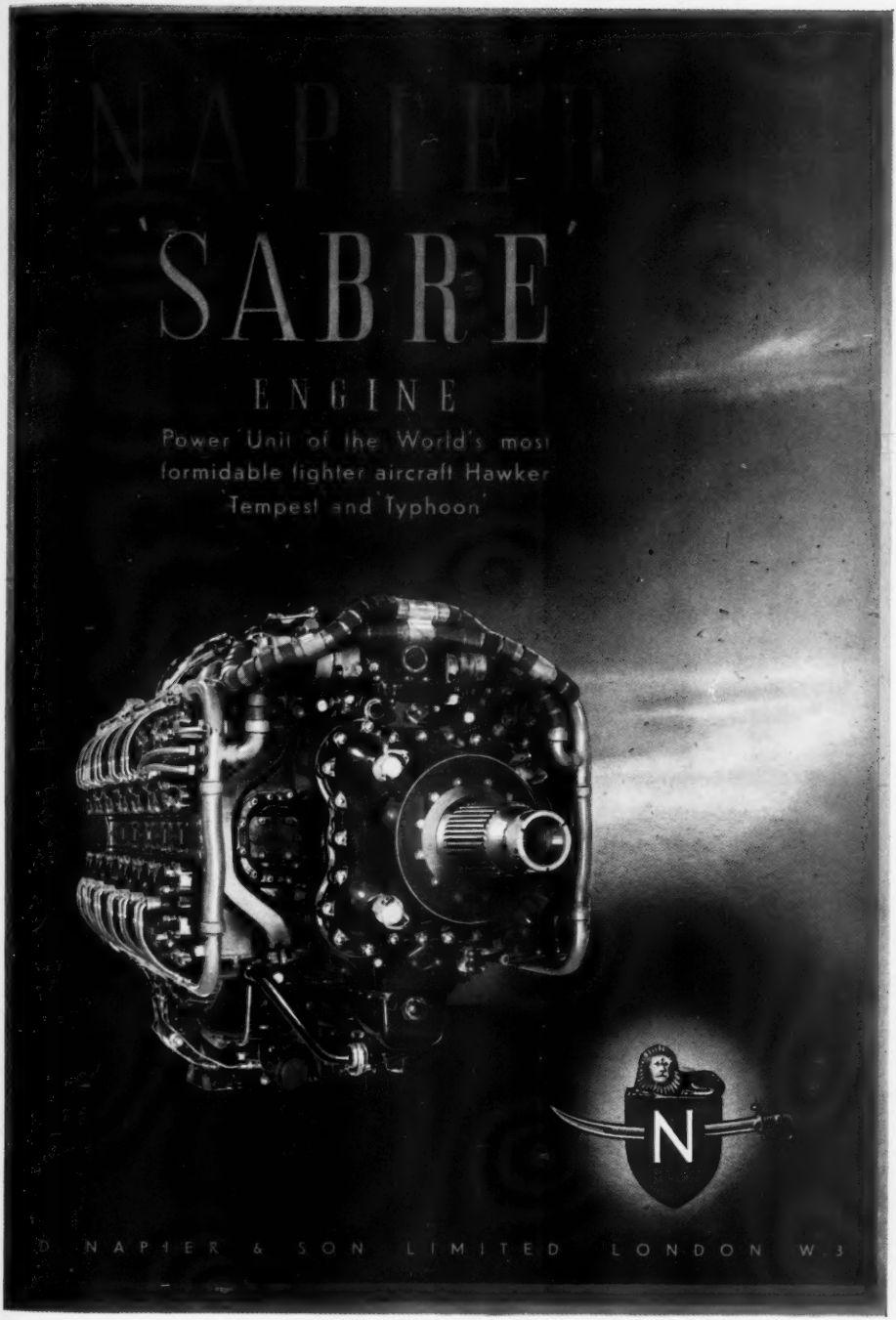
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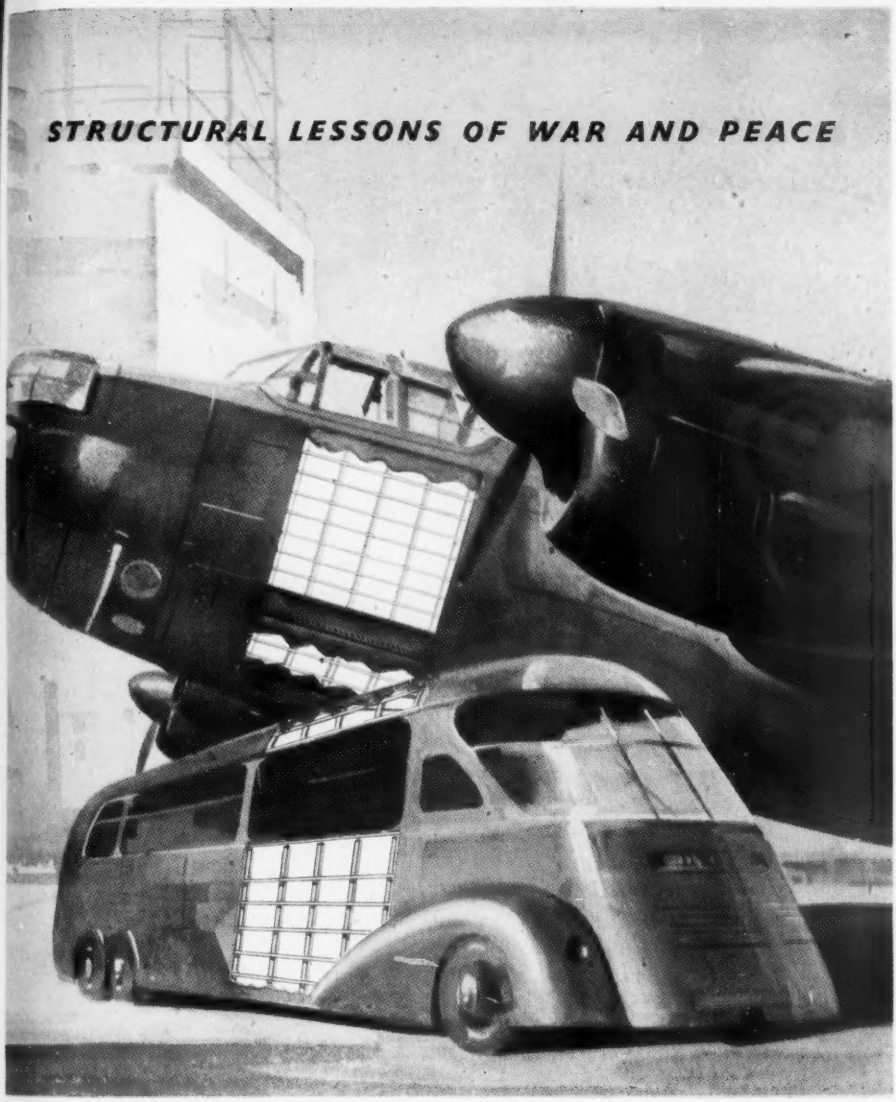

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